UTILITY OF ODOUR INTENSITY FOR THE MEAT PROCESSING INDUSTRY

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1.0 Executive Summary

Odour intensity is being increasingly considered as an alternative to odour concentration to quantify emissions from odorous industries, to prioritise sources for emission control and to determine which sources contribute most to objectionable odours off-site. This study presents a literature review of the use of odour intensity in Australia from an industry and regulatory perspective and discusses the odour intensity measurements that are available to date. A pilot odour sampling study was carried out for an integrated meat processing plant (IMPP) that consists of a beef abattoir, rendering plant and wastewater treatment facilities. The data collected were used to model both the odour concentration and odour intensity impacts from the site. The implications for odour management and regulatory assessment have been discussed.

The pilot odour study measured odour emissions from the biofilter, activated sludge press, cattle yards, cattle truck, aerated wastewater ponds and primary wastewater solids screen. These sources were also analysed for the odour concentration - intensity (OCI) relationship with the exception of the aerated wastewater ponds, for which the odour concentration was too low to determine the intensity.

Limitations of the odour sampling method include a lower bound of the odour concentration to determine the OCI relationship due to the olfactometry equipment used, differences in sampling method that yield different results (for example isolation chamber or ambient sample), and the lack of standard method for determination of odour intensity that uses the Australian Standard (AS/NZS 4323.3, 2001) for dynamic olfactometry. There is a clear need for further work on odour intensity for a range of sources, operating conditions and IMPPs, as well as using several laboratories to perform the analysis.

The use of odour intensity methods to set ambient odour criteria shows promising application to IMPP. The results of the pilot modelling study indicate that odour intensity can distinguish between odours that would be considered stronger or weaker at downwind receptors, thus allowing sources that might have a high odour emission rate but low intensity to be evaluated more realistically than current odour criteria allow. The interpretation of odour intensity results from multiple sources also needs to be clearly established.

The results of the pilot study suggest:

- An overall short-term odour threshold for annoyance of around 10 OU;
- Strongest odours are from the sludge press and cattle truck sources, but relatively weak odours are found from the primary wastewater screen;
- Biofilters substantially reduce the odour intensity of IMPP emissions as evidenced by a doubling in the critical odour concentration from the biofilter inlet to outlet, thereby halving its perceived strength;
- Major impacts at off-site receptors are due to the biofilter source (used to control rendering odours) and to a lesser extent the cattle yards; other sources can be treated less rigorously.
- Improvements in control efficiency of the biofilter is a major target for reducing odour impacts from this IMPP.

2.0 Introduction

This study looks at the use of odour intensity as an alternative method for assessing the acceptability of odour impacts from integrated meat processing plants (IMPP), which generally describes a red-meat abattoir with associated rendering facilities to produce edible by-products and wastewater treatment. Odour can cause annoyance or nuisance at sufficiently high levels, while the potential for odour impacts depends on many site-specific factors such as the strength and nature of the odour. The intent of most environmental legislation that relates to odour is to limit odour impacts to acceptable levels in the community.

Odour is usually described in terms of its concentration, with one odour unit being the level at which odour is detected. Odour intensity provides an alternative description of odour that describes the perceived strength or magnitude of the odour. Intensity increases non-linearly with increasing concentration, and is generally described on a scale of very weak to extremely strong. Odour intensity is described further in Section 3.0.

Odour emissions from most IMPP have the potential to be highly offensive due to the nature of the processes used. Many of the IMPP are now employing odour control techniques (such as biofilters, scrubbers, afterburners or ozone treatment) to reduce the odour released from their operations; however not all odours can be fully captured and treated.

Odour regulation for these facilities is often prescribed on the basis of meeting odour concentration criteria at the boundary of the site. This is demonstrated by the use of odour emission measurements at the key release points, and dispersion modelling to predict the boundary odour concentration. Alternatively, the presence of odour complaints from the local community is used to indicate that operations are not adequately controlling the emission of odours from the site. This odour measurement and regulatory process does not take into account the differing potential for annoyance from disparate odour sources or the other socio-economic factors that influence the transition between odour annoyance and the lodging of complaints. For example, smaller communities where an IMPP constitutes a significant employer may be more tolerant of annoying odours for a time.

Odour intensity has been used as an alternative method for assessing odour nuisance in the community from odorous sources. The poultry (broiler farm) industry has conducted research on the nature of odour concentration - intensity (OCI) relationships for their industry, and these are cited as alternative odour assessment criteria in Western Australia. Likewise, the pig and dairy industries have conducted several studies into odour intensity that are being considered in alternative odour guidelines (Jiang 2002).

2.1 Objectives of this odour intensity study

The objective of this project is to provide a fundamental basis for MLA and other interested parties to assist the future direction of odour regulation in Australia with particular regard to the use of odour intensity measurements as a tool for odour assessment and regulation for integrated meat processing plants.

The project includes the following:

- Critical review of odour intensity measurement and application to odour regulations.
- A case study that investigates the application of odour intensity measurements and dynamic olfactometry at an integrated meat processing plant.
- Assessment of the differences between measurement techniques and use in dispersion modelling.
- Implications for the meat industry for compliance with odour guidelines if odour intensity measurements were used instead of odour concentration.
- Recommended position for the meat processing industry on odour intensity in odour regulation.

The report structure first presents the role of odour intensity in assessment of odour impacts. Descriptions of odour intensity and guidelines that utilise odour intensity are presented, and compared with measurement of odour concentration. The different OCI relationships that have been developed are discussed, and available odour intensity measurements from publicly-available studies are presented. Section 5 presents the objectives and results of the pilot odour intensity study to establish OCI relationships for an integrated meat processing plant. These results are then used in dispersion modelling to establish the odour impacts of an IMPP in terms of either odour concentration or odour intensity. Different methods of analysing the results are presented, with comparison to Australian guidelines for odour concentration and intensity. Lastly, the implications for the use of odour intensity as an alternative assessment methodology for the meat processing industry are presented.

2.2 History of odour measurement

Odour measurement techniques have been developed since the 1970's in Europe, America, Asia and Australia. Comprehensive summaries of the different measurement standards have been done by the UK Environment Agency (2001) and Van Harreveld et al (1999).

Odour measurement in Australia has been through several stages of development using dynamic olfactometry, where a panel of assessors judges the concentration at which odour is first detected, corresponding to the detection threshold, or 1 odour unit (OU). Several Australian states developed their own measurement method using dynamic olfactometry for mixtures of odorous compounds such as found from meat processing plants. The Victorian B2 method was released in 1985 and the Queensland Method 6 was released in 1995. NSW used a method based on the Dutch NVN2820 method (1996). These standards have now been replaced by the Australian and New Zealand Standard AS/NZS 4323.3 (2001). Consequently, most older measurements of odour concentration are inconsistent with the Australian Standard results. The Australian Standard method is similar to the European CEN method that is now in use across Europe. Since the Australian Standard method was adopted across Australia, measurement laboratories are showing much better reproducibility between labs, although differences by a factor of 2-5 can still occur.

Odour intensity measurements have been adopted more recently in a few of the laboratories in Australia. The German VDI and American ASTM methods for odour intensity have been used at various times, with other groups offering services to conduct field observations of odour intensity. Odour intensity has been successfully applied to some industrial and agricultural odour sources to supplement odour concentration measurements.

2.3 Why are we interested in odour intensity?

Several Australian EPAs are now accepting or encouraging the use of source-specific concentration - intensity measurements to allow for different annoyance criteria for various odorous industries. It is generally accepted that the important odour characteristics that determine odour annoyance include the related quantities of odour concentration, intensity, hedonic tone and odour quality (Irish EPA, 2001). Hedonic tone is a subjective judgement of the relative pleasantness or offensiveness of odour, while the odour quality describes what the substance smells like (such as a description of 'fruity').

Some European countries have developed measurement standards for each of these, with Germany, for instance, giving guidance to field and laboratory measurements of intensity (VDI 3882 Part 1) as well as hedonic tone (VDI 3882 Part 2). In Australasia, various laboratories have developed add-on procedures to the concentration standard AS/NZS 4323.3 (2001) to include intensity measurements similar to the German industry guideline VDI 3882.1 (e.g. Schultz 2002). There is continuing debate on technical issues such as reproducibility, analytic method and need for acknowledgment of panel sensitivity, as shown by a recent workshop discussion on odour intensity at the CASANZ conference (2003).

Measurements elsewhere have shown that hedonic tone and intensity are inter-related and that there is a wide range in thresholds that lead to detection, recognition and offensiveness through a representative population (Nicell 2003). Odour intensity measurements give little guidance of the potential of a given odour to cause offence and may only be a first, but welcome, step to the differentiation of odour types for impact assessment. For some source types, the intermittency and persistence of odours may be as important in causing nuisance - the UKEA survey on community response to odours (UK Environment Agency 2002a) recommended the use of both hard (quantitative) and soft (ranked score) factors. A recent review of soft factors and the physio-psychological basis of odour annoyance (Best et al 2004) emphasised the rather narrow focus of past regulatory approaches and the apparent denial by many of links between odour annoyance and temporary health ailments. Another confounder is the recent suggestion that fine dust can carry odour (possibly adding 30% to the concentration measured via conventional olfactometry). This has the potential to give systematic differences between field and laboratory measurements of intensity.

Australian methodologies to date have either excluded odour sources from modelling if intensities are below 'distinct' (I=3), or defined an impact threshold in terms of concentration from an intensity level of 3 (or sometimes 2), with little consideration yet of offensiveness via hedonic tone measurements. Such approaches are beginning to allow regulatory efforts to be better focussed on sources with a high potential for off-site impact. These considerations should be set in a wider context of assessing nuisance criteria for the wide range of odour mixtures found in meat processing plants. This is an extensive area for innovative measurement technologies and indeed, artificial intelligence techniques such as electronic noses have been successfully trialled to give automatic indicators of concentration, intensity and hedonic tone.

The consideration of odour intensity for IMPP is particularly useful as these plants tend to have a variety of odour sources, often with dissimilar characteristics and different source structures (such as surface pond emissions or medium-height stack emissions). Odour regulations that apply a single odour concentration criterion to such diverse sources can result in large impacts being predicted by the modelling, which is not always verified by community complaints. Further discussion on the general odour issues for IMPP is provided in Appendix 2.

2.4 Previous odour research work for MLA

In recent years, MLA has funded a number of odour research projects for the meat processing and rendering industries. Some important issues that underpin this work relate to how to characterise odour emissions in a way that is cost-effective, practical and that provides information that can be used for resolving odour nuisance issues. Dynamic olfactometry cannot provide this information on its own and in particular cannot explain why two odours with equivalent concentrations may have very different potentials for causing odour nuisance. Routine collection of odour intensity with dynamic olfactometry could enhance our ability to answer this question.

MLA ("Investigation of odorous gas emissions from meat and rendering plants", 1999a) investigated odour measurement techniques including olfactometry, Gas Chromatograph-Mass Spectrometer (GC-MS) and electronic nose for use in odour assessment in the meat processing and rendering industries. A total of 55 odour samples were collected from a range of sources from two regional abattoir/ rendering plants and three service rendering plants. Odour samples were analysed for odour concentration using dynamic olfactometry (in accordance with the then current draft Australian and CEN standards) and for chemical constituents by GC-MS (based on USEPA TO-14).

This study concluded that olfactometry is one of the most practical techniques for odour auditing, quantification of odour emissions and evaluating odour control system performance. The most important odorants were found to be reduced sulphur compounds (hydrogen sulphide, dimethyl sulphide, dimethyl disulphide and methyl mercaptan) and aldehydes (3-methyl butanal, 2-methyl butanal, 2-methyl propanal and heptanal). Amines were found to be important odorants at two of the plants. The chemical groups were found to be a practical means of differentiating sources within plants and between plants. Plants receiving older raw materials were found to have higher proportions of reduced sulfur compounds.

Electronic noses were found to be promising technology for differentiating between odour samples from the five plants and for samples with different strengths. Further evaluation of second generation electronic nose technology for application to meat processing and rendering industries was recommended. The SPME gas chromatographic method, may be a practical and less expensive alternative to the traditional GC-MS techniques for moderately strong odours.

MLA ("Biofilters for control of rendering odours", 1999b) reported on biofilters for controlling odour from rendering plants. Two pilot biofilters and one demonstration biofilter were constructed to treat non-condensable vapours from rendering. An odour reduction rate of better than 90 % was achieved in the Townsville pilot biofilter. Odour levels of 3,300 OU in the outlet of a demonstration biofilter did not appear to cause nuisance. Whilst the authors concluded that the performance of the biofilters was satisfactory, concern was expressed about the 'background odour' associated with the biofilter media. Qualitative observations suggest that the odour associated with the biofilter media may be significant directly above the source, but this odour does not travel far and may be indistinguishable at about 3 to 4 metres.

Unpublished work for MLA ("Determination of meat industry odour thresholds", 2003) by Pacific Air and Environment undertook odour intensity emission sampling of a rendering plant roof emission and field odour intensity observations over a 30 minute period at an undefined downwind distance from a rendering plant (Plant 2) located in hilly terrain in New South Wales. The key points of interest of this report are:

- The downwind odour was found to be of intensity between I = 1-2 with both rendering odours and a urine-like odour from the holding yards being detected.
- The rendering emission sampling gave values for the odour concentration ("odour units above threshold") of 1.5 OU for I = 2 and 5 OU for I = 3.
- Simulated peak-to-mean ratios were 5-15 for two field sites at another plant (Plant 3).
- Recommendations of annoyance criteria for the three plants of 1.5 OU for the 99th percentile hourly concentration and around 1 OU for the 98th percentile hourly value.
- A claim that plume buoyancy effects are important even for surface sources.
- Complaint zones occurring where predicted concentrations are around 1-5 OU for a 99.5th percentile and 1 OU for a 98th percentile of the predicted concentrations (based on a 1 year simulated meteorological data file and one set of emission measurements).

These findings are of considerable interest, but some aspects require further assessment and evaluation, including:

- Intensity measurements of the cattle yard emissions are needed.
- Should rendering and cattle yard odours be assumed to be additive?
- Should the temporal variability in the odour emissions be accounted for?
- Should peak-to-mean ratios be more realistically applied? The standard peak-to-mean ratio for volume sources has been applied too all sources on site, thus ignoring the peak-to-mean ratios determined by field observation in the study.
- There is little difference between the suggested complaint and annoyance criteria.

Indeed, the deduced peak-to-mean ratios of 5-12 taken together with the dispersion modelling would suggest that the 99th percentile nose-response time concentrations are around 10-20 OU for odour complaints and 5-10 OU for odour annoyance. The latter value seems sensible in light of the single OCI curve for the rendering odour and suggests that the odour for IMPP may be weaker than piggery and poultry odours, for example.

2.5 Key odour issues facing IMPP

Odours from IMPP have been the cause of many odour complaints and community nuisance, particularly in situations where new residential areas encroach on established industries. Different expectations of odour exposure, acceptance of the industry that causes odour and tolerance to rural-industrial types of odour are key factors in how a community may be affected.

Traditional odour assessments for IMPP have been based on odour concentration measurement using olfactometry and achieving a generic odour criteria at the boundary, or nearby residential receptors. The following issues are encountered:

- Assessment is based on odour concentration, and does not account well for the other dimensions of odour namely intensity, hedonic tone and odour quality.
- Impacts from all sources are treated equally, with odours from each source simply added together.
- Predicted impacts do not always correlate with complaints or odour surveys.
- Traditional odour modelling can provide a basis for designing control equipment and mitigation measures. However, this approach may over-estimate the level of odour control needed.
- The assessment requires good data inputs (source emissions, site-specific meteorology), but becomes costly to collect sufficient data to fully characterise source variability.
- Compilation and analysis of odour emission data from different IMPP sites would be a useful means of establishing variability whilst minimising the cost of sampling.
- Residential encroachment (increasingly occurring due to changes in planning laws) can cause complaints and community annoyance from an established industry that was compliant with odour legislation. Retrofitting best practice technologies is the only option for many sites, but may not guarantee that annoyance is eliminated and hence is not cost-effective.

Odour intensity can be used at IMPP to help with the following issues:

- More realistic assessment of odour control devices that change the strength of the odour (such as biofilters and scrubbers).
- Better treatment of sources that are relatively weak and therefore have minimal impacts off-site.
- More appropriate treatment of strong sources, that may cause proportionally more odour impact off-site.
- Improved identification of problem sources that will benefit the most from source odour reduction strategies.
- Development of odour criteria that are more appropriate for meat processing plants, and that do not place generic limits that may be unachievable on the odour impact from such industries.

3.0 Odour intensity in odour assessment

3.1 The overall odour assessment philosophy

All Australian state jurisdictions have legislation that, in some way, protects the general community from objectionable or nuisance odours caused by commercial and industrial activities. Most jurisdictions have powers to compel major industry to investigate and assess reported odour problems. Most planning authorities expect new development proposals that will emit odour to demonstrate that emissions are managed and controlled to the extent that they do not adversely affect the amenity of more sensitive land-uses.

Odour assessments are commonly undertaken for three broad reasons:

- To assess the impact of a new development proposal that is known to emit odour and may affect the amenity of sensitive land-uses. Conversely, to assess the impact of an existing industry on a new development proposal that places a sensitive land-use close to an existing industry that is known to emit odour

- To aid in the design of odour control strategies for existing developments that are known to cause odour impacts on sensitive land-uses.

- To investigate odour complaints or odour nuisance occurring in an area where the cause is unknown and where there are a number potential sources.

The main factors that influence whether a person finds a particular odour a nuisance or annoyance and that may cause that person to complain to regulatory agencies about the odour are:

<u>Frequency:</u> how often does the person experience the odour?

<u>Intensity:</u> how strong is the odour?

<u>Duration:</u> how long does the odour last?

<u>Offensiveness/character:</u> how pleasant or unpleasant is the odour?

<u>Location:</u> where was the person when the odour was observed?

<u>Coping strategy</u> and <u>odour sensitivity</u> of the affected person.

For existing plants, odour sources can readily be identified. Quantification of odour, preferably accounting for temporal and spatial variability in the emissions, could use either olfactometry to measure source characteristics as inputs to dispersion modelling, or alternative techniques for measurement of near-source ambient odours (e.g. Nasal Ranger, Stephenson et al 2004).

The most common odour impact assessment techniques use measurements of odour emission rate (based on dynamic olfactometry) and dispersion modelling to estimate odour impacts. Such assessments can provide useful information to plant operators and regulators on the potential impact of odour emissions. However, such assessments provide only part of the picture. The frequency and location of impacts and to a lesser extent duration can be adequately characterised by a dispersion model but the intensity is often characterised by odour concentration, which is an incomplete substitute that does not account for the variability in odour intensity/concentration relationships for different odour types. The offensiveness or character of the odour is mostly ignored. Consequently, these assessments can be misleading as to the real driver of odour problems and may result in odour control strategies that are not sensible.

For example, biofilters are often used to treat odours at sewage treatment plants. Biofilters can be very effective in reducing offsite odour impacts if they are appropriately designed and well maintained. However, odour sampling and analysis by dynamic olfactometry at sewage treatment plants often show that the biofilter is a major component of odour emissions from the site in terms of the odour emission rate. Odour emissions from biofilters are often attributed to the natural odour of the packing material (such as pine bark or soil). If this is the case, odour intensity measurements may provide a 'quantitative justification' for ruling a well-run biofilter out of future odour assessments. Intensity measurements also provide an alternative means of assessing the effectiveness of odour control.

Similarly, the 'background' odour of the packing material is suspected of contributing substantially to the odour emission rate from abattoir and rendering plant biofilters. This odour is reported to not travel far (MLA "Investigation of odorous gas emissions from meat and rendering plants", 1999a) and consequently may be indistinguishable at 3 to 4 metres. Intensity measurements should provide a means of quantifying why biofilter odours are less important for odour impacts despite sometimes being emitted at relatively high emission rates.

3.2 Odour intensity

Odour intensity is the strength of an odour that is perceived by the human sense of smell. It is equivalent to other concepts that relate the general human perception to physical measurements of the stimuli. Similar concepts include the heaviness of an object or the loudness of a sound. Odour intensity differs from odour concentration in the same way as loudness differs from the vibrational energy that produces sound waves. Humans can perceive stimuli across a very wide range of levels; for example, there are about 13 orders of magnitude of energy level from the very faintest sound that can be perceived to the loudest sound that is close to the threshold of pain. However, human hearing finds it difficult to perceive small changes in the vibrational energy of sound. A doubling in sound energy is required to give an audible difference in the sound (about 3 decibels) whilst a 10-fold increase is required to double the perceived volume.

Annoyance due to noise requires consideration of loudness statistics, tonality, impulsiveness and the behaviour modification (e.g. adaptation and sleep deprivation) caused by noise. Odour sensors in the nose have a more direct connection to the emotional part of the brain whilst the range of coping mechanisms to an odour disturbance can be quite wide. The intermittency and offensiveness of odours are often key factors in causing annoyance.

Odour intensity and odour concentration measurements can be related by a logarithmic function as a means of understanding the perceived strength of an odour that may be associated with an odour concentration. The odour intensity scale is commonly defined by odour descriptors that express how strong the odour is to the observer. The scale most commonly used is the VDI 3882.1 scale that ranges from 'not perceptible' to 'extremely strong' (Table 1), with the numerical scale from 0 to 6 used to represent each descriptor in ascending order of strength. Larger or smaller scales are also used, including: 4, 5, 6, 8 and 11-point scales (Chen et al 1999a). For many odours, the relationship between odour intensity and the logarithm of odour concentration has been found experimentally to be essentially linear. The VDI 3882.1 method for determining odour intensity in conjunction with olfactometry predates the Australian Standard (AS/NZS 4323.3) for dynamic olfactometry and thus requires modifications if it is to be used with the Australian Standard (Schultz 2002, 2003 and Pitt 2003).

Table 1. VDI 3882.1 odour intensity descriptors

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

The relationship between odour intensity (I) and concentration (C) can be illustrated by the odorous compound n-butanol. The odour detection threshold for n-butanol specified in VDI 3882.1 is 46 ppb (defined as 1 OU). The logarithmic function that can describe the relationship between odour intensity and n-butanol concentration is:

$I = 1.65.\log(C) - 2.24$

Using this relationship, a concentration of 46 ppb (1 OU) corresponds to an odour intensity of between very weak and not perceptible (I=0.5). Doubling this concentration to 92 ppb (2 OU) increases the odour intensity to very weak (I=1.0). Increasing this concentration by an additional factor of four to 368 ppb (8 OU) increases the odour intensity to weak (I=2). Increasing this concentration by another factor of four to 1472 ppb (or 32 OU) increases the odour intensity to distinct (I=3). For n-butanol, there are about 3 orders of magnitude of concentration between intensity levels of 'very weak' (92 ppb, or 2 OU) and 'extremely strong' (98614 ppb, 2143 OU).

The use of odour intensity for odour assessment often refers to the equivalent odour concentration that corresponds to a selected intensity level. This critical odour concentration (COC) is expressed as COC_W for an odour concentration that equates to an intensity of weak, and COC_D for an intensity of distinct. A low COC implies that an odour is perceptible at a low odour concentration and is considered to have a high potential for impact. Conversely, a high COC implies an odour with a low potential for impact.

A complicating factor for the relationship between odour intensity and the logarithm of odour concentration is that the gradient of the linear relationship varies depending on the properties of the odour. This gradient is a useful measure of the relative importance of an odour. Odours that have a large gradient are more likely to be evident off-site at lower concentrations than odours with relatively small gradients.

3.3 Odour guidelines based on concentration

Assessment of odour impacts has traditionally used odour concentration criteria to determine whether a particular industry will cause odour impacts. These criteria are based on the measurement of odour using the Australian Standard method (AS/NZS 4323.3, 2001), with each state assigning their own odour concentration criteria, averaging time and percentile for compliance. Due to the transient nature of odours, and the response of the human nose which can be instantaneous, short averaging times of 1-hour or less are used. The NSW DEC has also adopted the use of nose-response-time concentrations, which are estimated from 1-hour average dispersion modelling results using peak-to-mean factors which depend mainly on source type, the distance from the source and atmospheric stability. A 3-minute averaging period is used in Victoria, SA and WA, with a 1-hour averaging period adopted in Queensland and Tasmania. The Queensland guideline also uses peak-to-mean ratios to differentiate between the impacts from stack and wake-affected sources.

The odour concentration guidelines used in various Australian states are summarised in Table 2. Measurement of odour is conducted using the Australian Standard method for dynamic olfactometry. The 3-minute average guidelines are also presented as equivalent 1-hour average guidelines using a factor of 1.4, as noted in WAEPA (2002). This factor is applicable to near-surface sources only.

Table 2. Odour concentration guidelines used in Australia

State	Odour level using Australian Standard measurement method {equivalent 1-hour concentration in braces [1]}	Averaging time	Percentile for compliance
Queensland	2.5 OU (for ground-level sources and downwashed plumes from short stacks) 0.5 OU (for wake-free point sources)	1-hour	99.5th
NSW	2 OU (population >=2000 or a school) 3 OU (population 500 - 2000) 4 OU (population 125 - 500) 5 OU (population 30 - 125) 6 OU (population 10 - 30) 7 OU (single residence, <= 2)	Nose-response time (1-second) [2]	99th
Victoria	1 OU {0.7 OU} [3]	3-minute	99.9th
WA	2 OU {1.4 OU} and 4 OU {2.9 OU}	3-minute 3-minute	99.5th 99.9th
SA	2 OU {1.4 OU} (population >= 2000) 4 OU {2.9 OU} (population >= 350) 6 OU {4.3 OU} (population >= 60) 8 OU {5.7 OU} (population >= 12) 10 OU {7.1 OU} (single residence)	3-minute	99.9th
Tasmania	2 OU	1-hour	99.5th

Note [1] Based on 1-hour concentration = 3-minute concentration / 1.4.
[2] Calculated from 1-hour average model predictions using peak-to-mean ratios as noted by NSW DEC (2001).
[3] The Victorian SEPP (AQM) also specifies a guideline of 5 OU (3-minute average, 99.9th percentile) for intensive animal husbandry, however this is not appropriate for a rendering plant.

The population-dependent guidelines used in NSW and SA include a pseudo risk assessment, in that a higher number of people exposed to odour in a large town will also include a greater number of people that may be highly sensitive to odour, and therefore more likely to experience odour nuisance.

3.4 Odour guidelines based on intensity

OCI relationships that are developed for a specific industry or odour type can be used in Western Australia and Queensland to develop alternatives to standard odour concentration criteria. The odour concentration that corresponds to a particular odour intensity is termed the 'critical odour concentration' and is used as the threshold for odour regulation in place of a general odour concentration guideline. The COC is combined with an appropriate averaging time (for example a 3-minute average) and a percentile of compliance (for example 99.5^{th} percentile). In this manner, industry-specific odour guidelines can be derived once the appropriate OCI relationships have been determined. The selection of averaging time and percentile compliance are as important as the threshold to define the conservatism of an assessment.

The selection of an odour intensity level for compliance depends on the legislative requirements of the jurisdiction and the amenity values that are to be protected. For example, protecting against odour detection or recognition may lead a jurisdiction to choose the odour intensity level of 'weak' (I=2), while annoyance or nuisance may be avoided by using an intensity level of 'distinct'.

Western Australia uses odour concentration criteria for assessments. However, for proposals that do not meet the screening criteria, proponents may undertake an odour intensity study to provide greater certainty about the odour impact of the proposal, and specifically to determine the odour concentration equivalent to the intensity level of 'distinct' (I = 3). Criteria are intended to be applied to area, volume and wake affected sources. A peak-to-mean approach is being developed for line, surface point and tall wake free plumes. The COC_D is used as the odour criteria with a 3-minute averaging period and 99.5^{th} percentile. For poultry farms, a concentration of 7 OU corresponds to 'distinct' odour intensity.

In Queensland, the odour guideline (QEPA, 2004) allows an alternative odour guideline to be determined from the critical odour concentration that corresponds to an odour intensity of 'weak' (I = 2) that is derived from an odour intensity/concentration relationship. The alternative odour guideline is set to be equivalent to the COC_W with an averaging period of 1-hour and a 99.5^{th} percentile and multiplied by the relevant default peak-to-mean factor (0.5 for ground-level or downwashed plumes from short stacks, and 0.1 for tall stacks).

The use of odour intensity-derived guidelines in Queensland and WA are based on assessments for a single source. Sites that have multiple odour sources with dissimilar characteristics, such as those found at IMPP, have not been accounted for in these guidelines. This report investigates several ways to use the different odour intensity-concentration curves for multiple sources in Section 6, that implements the intent of the Queensland and WA odour intensity guidelines.

Other approaches to odour regulation using intensity

An alternative approach to odour regulation, that has the advantage of eliminating the need to undertake dispersion modelling, would require an odorous activity to demonstrate that the intensity of odour emitted from all sources is below an odour intensity level of 'distinct' or 'weak'. Clearly, a source that has an odour intensity at the point of emission that is 'distinct', 'weak' or less is not likely to be more evident (stronger) off-site after some dispersion has taken place. This approach can also be used to prioritise limited resources for odour measurement, assessment and treatment to target sources which are the most evident off-site. It is sensible in most assessments to eliminate sources that emit odour at an intensity that is below a level of 'weak' from further odour assessment or consideration for mitigation.

For sources that have an odour emission rate that is difficult to measure (such as a passively ventilated building), an OCI relationship may be able to be derived that shows that additional source characterisation is not required. This could save sampling costs and eliminate what may be a considerable uncertainty from the assessment.

3.5 Quantifying odours

There are various laboratory and field techniques available for quantifying the amount of odour released from an odour source and the impact of the odour release on sensitive land-uses. Some of these techniques are recognised in environmental legislation and regulators require or recommend that these techniques be used for assessing impacts or compliance. Others are experimental or are being developed and may not have achieved broad agreement within the scientific and regulatory community for general use. A summary of available methods follows.

Laboratory odour concentration by dynamic olfactometry

Odour concentration measurements have been undertaken for a number of years in Australia. Prior to 2001, there were a number of different methods for measuring odour concentration by dynamic olfactometry. The various methods recommended by state jurisdictions were not equivalent and were recognised as providing widely varying results and performing poorly in repeatability tests.

In 2001, the Australian/New Zealand Standard (AS/NZS) 4323.3 – "Stationary Source Emissions – Part 3: Determination of odour concentration by dynamic olfactometry" was published. This standard was derived from a draft version of the European standard EN13725 (CEN 2003). The development of the Australian Standard should improve repeatability of odour concentration measurement within a laboratory, improve reproducibility of odour concentration measurement between laboratories and provide traceability to a standard odorant – n-butanol.

The Australian/New Zealand standard improves laboratory repeatability by defining critical aspects of the analysis method including: the materials of construction of the olfactometer, ascending order for presenting samples to the panel, forced choice selection from two or more ports, number of panellists, periodic calibration and n-butanol as the reference odorant.

Inter-laboratory comparisons undertaken by the Victorian EPA (Bardsley 2002) comparing laboratory performance using AS/NZS 4323.3 and the EPA Vic Method B2 (EPA Vic 1985) concluded that the Australian Standard method showed dramatically better within laboratory repeatability and inter-laboratory reproducibility. The results support the Victorian EPA's adoption of AS/NZS 4323.3 for odour analysis in Victoria.

All other Australian state jurisdictions support the use of AS/NZS 4323.3 for odour analysis.

Laboratory odour intensity

A standard method for determining odour intensity in a laboratory has been published by the German engineering association (Verein Deutscher Ingenieure or VDI). The primary function of the VDI is the transfer of technical knowledge as a service to engineers and students. In the last 40 years the VDI has compiled 1700 technical guidelines. VDI 3882.1 *Olfactometry; determination of odour intensity 1992* employs the use of supra-threshold olfactometry analysis to assess the intensity of an odour (Schulz 2002). Odour intensity is referenced against a 7 point scale that is reproduced in Table 1. This method uses the corresponding VDI 3881 method to determine odour concentration, which is based on dynamic olfactometry techniques that pre-dated the Australian Standard method AS/NZS 4323.3 (2001).

The publishing of the WA EPA odour guidelines with reference to odour intensity has initiated an important debate amongst odour laboratories and the broader regulatory and scientific community about whether VDI 3882.1 can be used or adapted for determining odour intensity in a laboratory in conjunction with AS/NZS 4323.3 (2001). It is clear from this debate that:

- VDI 3882.1 needs to be modified to use in conjunction with AS/NZS 4323.3;
- There is not a consensus on all critical aspects of odour intensity measurement; and
- It is important that a standard method is developed for measurement of odour intensity. The experience with using various dynamic olfactometry methods across Australia prior to the development of AS/NZS 4323.3, indicates that a failure to develop an odour intensity standard will lead to the waste of research resources.

As with any developing field, there is considerable debate amongst olfactometry experts as to the measurement and analysis methods that should be applied for odour intensity determination. Some of these issues are discussed in Appendix 1. Key points are:

- The potential for contamination of equipment needs to be addressed, particularly if random presentation of odour samples (instead of ascending concentration) is to be successfully used.
- The averaging time that is relevant for an odour intensity sample.
- What odour intensity is critical for community annoyance and protection.
- What form should the OCI relationship take, and should an odour concentration of 1 always correspond to an intensity of between 0 and 1.

Field odour determinations

Field odour determinations can be made by observers reporting odour intensity in accordance with a standard procedure. A method for field measurements of odour intensity has been formalised in the German standard VDI 3940. The American standard ASTM E544-75,88 is also used for field determination of odour intensity by USEPA field inspectors. Schulz et al (2002) and Ormerod et al (2002) have used field measurements of odour intensity based on the German standard VDI 3940 to identify the mean and peak odour concentrations that may be experienced downwind (based on laboratory determinations of the OCI relationship) and to validate the results of dispersion modelling.

Stephenson et al (2004) discuss the different devices that can be used to assist in field measurement of odour intensity, by providing odour-free air to avoid fatigue and pre-determined dilution ratios of ambient air to odour-free air. These devices have become standard practice for regulatory assessments in the United States. They claim that the use of a calibrated field olfactometer and trained operator is a cost-effective and real-time way of quantifying odour strength. However, some experts in odour measurement have reservations about the potential for contamination of the device.

Field odour determination is a promising area that could help to remove some of the considerable uncertainties associated with relying on complaints and dispersion models to demonstrate that annoyance might be occurring. The general community, regulators, industry and courts will have substantially more confidence in actual observations of odour in the field. However, there are some challenges to overcome relating to defining acceptable methodologies, establishing the sensitivity of observers, avoiding desensitisation that occurs due to repeated exposures to the same odours and defining criteria for acceptability and nuisance.

Odour annoyance

Some standard approaches to quantifying odour annoyance are published by VDI (3883.1 and 3883.2). These approaches have been used to a limited extent in Australia, most often as the basis of odour reduction studies and to develop odour concentration criteria from dispersion modelling.

Hedonic tone measurement

VDI also has a method for determining hedonic tone (VDI 3882.2), which has been used by some laboratories in Australia. The relationship between hedonic tone and odour concentration has been determined experimentally for odours from pigs (Lim et al, 2001).

4.0 Odour concentration - intensity measurements

It is very important that a standard Australian method be developed for analysing odour samples for odour intensity. Despite this, various laboratories in Australia have measured odour intensity by adapting the VDI 3882.1 method to use with olfactometry done by the Australian Standard (AS/NZS 4323.3 2001) method.

Several different models for the odour concentration - intensity (OCI) relationship have been proposed. The best known is the Weber-Fechner law, which is a log-linear relationship. Steven's power law has also been found to give good correlations, while the Beidler law is rarely used. Details of these relationships are presented below.

4.1 Models

VDI 3882.1 provides a summary of the derivation of Weber-Fechner law, a critique of the Weber-Fechner law by Stevens and derivation of Stevens' power law function. VDI 3882.1 assumes that the Weber-Fechner law adequately describes the relationship between odour intensity and odour concentration. VDI 3882.1 states that "…the intensity levels and the 50th percentiles of the stimulus level are also related to each other by the Weber-Fechner law…" and also "…the Weber-Fechner coefficient k_w (slope of the function) is not subject to any severe variations when the intensity variations of pure substances, unspecified mixtures or crude and clean gases are compared. The absolute value of the mathematically determined coefficients is affected by the basic scope of the data and by possible 'ceiling effects' at the top end of the intensity scale…".

Chen et al (1999b) investigated four models to describe the relationship between odour intensity and odour concentration. They found that the widely used Weber-Fechner law performed worst of the four models (r^2 = 0.8 – 0.9). The two power law models (r^2 = 0.94 – 0.97) and the Beidler model (r^2 = 0.97 – 0.99) described the data effectively. The Beidler model showed the best fit of the data and was used as the model to represent the relationship between odour intensity and threshold dilution ratio for swine buildings.

Krailas et al (2004) investigated the relationship between odour intensity and isopropanol using the same four models as Chen et al (1999b). It was found that the Weber-Fechner model best described the relationship between intensity and isopropanol concentration. This study of a biofilter, used to remove isopropanol, also found that the presence of acetone vapours at concentrations less 17 % do not affect the use of odour panel studies to estimate the isopropanol concentration from the experimentally derived OCI relationship.

Weber-Fechner law

This law is mainly founded on experiments where persons were given two nearly identical stimuli (for example, two similar weights) and tested whether they could notice a difference between them. The smallest noticeable difference was found to be roughly proportional to the intensity of the stimulus. So, if a person could consistently feel that a 110 g weight was heavier than a 100 g weight, he could also feel that 1100 g was more than 1000 g.

$I = k_w.\log(C/C_o) + \text{constant}$

The Weber-Fechner law is used in this report as it is the most straightforward to derive from experimental tests, and it is the preferred model in VDI 3882.1.

Stevens' law

This law is founded on experiments where two stimuli of different intensity were given, and the persons asked to quantify how different. For example: "is this sound twice as strong as that sound?" Stevens found that results from different sensory modalities (pain, light, sound, pressure) varied too much in "steepness" to be fitted by the Weber-Fechner law. Instead he introduced a formula with one more parameter, and therefore more flexible:

(i) General psychophysical model:

$I = k_1(C)^{k2}$

(ii) Adapted general psychophysical model:

$I = k_1(C - Cs)^{k2}$

Beidler model

This model is described by a sigmoid function as follows:

$I = k_1.k_2.C/(1+k_2.C)$

4.2 Summary of literature measurements of odour intensity

A summary of the Weber-Fechner law parameters for measurements of OCI relationships determined in Australia and internationally are summarised in Table 3. The table provides a summary of parameters for line-of-best-fit for OCI relationships using the Weber-Fechner law. The gradient of the line is $\mathbf{k_w}$ and the constant is the odour intensity equivalent to an odour concentration of 1. The critical odour concentration (COC_D) is also summarised, which is an odour concentration corresponding to an odour intensity level of 3 (distinct).

Table 3. Weber-Fechner law parameters for odour concentration - intensity measurements

Odour source	k_w	Constant	COC_D (OU)	Reference
Pig slurry	1.61	0.45	38.4	Misselbrook, Clarkson and Pain (1993)
Piggery	2.66	1.4	4	Jiang (2002)
Poultry farms (broiler and egg)	2.28	1.08	7	Jiang and Sands (1997), RIRDC (2000)
Poultry farms (Broiler shed)	2.35	0.3	14.1	Misselbrook, Clarkson and Pain (1993)
Dairy Farms	3.08	0.5	6.5	Wang and Feitz (2004)
Landfill (ambient)	1.89	2.43	2	Schultz et al (2002)
Alumina refinery stack	2.95	0.71	6	Schultz et al (2002)
Alumina refinery liquor, after thermal oxidation	1.39	1.11	23	Schultz et al (2002)
Oil extraction plant stack (hydrocarbon odour)	2.11	1.21	7	Schultz et al (2002)
Woolscour wastewater treatment plant, at steam stripper	2.51	2	2.5	Schultz et al (2002)
Rendering plant odour			5	MLA (2003)
n-Butanol reference gas	1.38	1.2	20	Schultz et al (2002)

Considerable variability in the COC_D can be seen for these different industries, and also for different studies on the same type of industry (for example broiler sheds and piggeries). The results indicate that landfills, wool scour plants and piggeries give off the strongest odours and thus are most likely to cause odour annoyance in the community. Rendering plants, alumina refinery stack, dairy farms, poultry farms and oil extraction plants rate as medium-strong odour, while the alumina refinery liquor and pig slurry results have relatively moderate odour. A single odour concentration guideline is clearly not appropriate to cover this diversity of odour sources.

5.0 Pilot odour intensity sampling study

5.1 Objectives and scope

The pilot study aimed to determine the odour concentration and corresponding odour intensity from various sources at an integrated meat processing plant (IMPP). The study outcomes were primarily aimed at characterising the OCI relationship rather than a definitive audit of all odour-generating sources on site. In this respect, some of the less odorous sources were not sampled while repeat samples on the important biofilter unit were performed.

5.2 Facility sampled, odour laboratory and variety of sources

The plant selected was a large abattoir and rendering facility and has a variety of odour sources, including the use of widely accepted odour control technology (eg biofilter), cattle yards and a good standard of waste-water treatment. Recently, the rendering facility was upgraded to include the installation of a biofilter to meet current best practice in odour minimisation. The rendering plant is fully enclosed, with the highly odorous process air as well as the room ventilation air being ducted to the biofilter. Cattle are unloaded from trucks directly into holding areas which are fully covered with open sides. These areas are hosed down after each pen is emptied, to minimise the potential for odour nuisance.

The waste-water treatment at this site entails primary screening of solids, with the majority of the biological degradation conducted in two aerated tanks. Further processing is carried out in a clarifier using activated sludge before licensed discharge to the sewer.

The sampling program was undertaken over two separate days in winter. The sources monitored were all atmospheric release points (with the exception of the biofilter inlet) and are as follows:

- Biofilter inlet (process air and room ventilation air, 2 duplicate samples taken)
- Biofilter outlet (4 samples taken on separate release points)
- Cattle yards (using one ambient and one isolation chamber measurement) and cattle truck
- Primary wastewater screens (collected solids)
- Aerated wastewater ponds
- Activated sludge dewatering belt press

EnvironOdour was the laboratory used for the sampling and analysis, with all equipment required shipped from Sydney to perform the sampling, while odour samples were returned to Sydney for analysis. Odour sampling and dynamic olfactometry were conducted according to the Australian Standard method (2001). Determination of odour intensity was conducted using the VDI 3882 method with an adjustment to accommodate odour concentrations measured by the Australian Standard. Appendix 3 contains the full report by EnvironOdour for the odour concentration and intensity measurements.

5.3 Odour concentration and odour intensity sampling results

Odour concentration results for all samples are presented in Table 4, with details of the ambient and process conditions during sampling given in Appendix 3. Specific odour emission rates are presented for isolation chamber samples only. The odour emission rates have been estimated for all sources, based on either the volumetric flowrate or surface area of the source.

Based on odour emission rates from each of the sources monitored, sources are ranked for odour concentration as follows: Biofilter inlet (not an atmospheric release point); Biofilter outlet (total of 4 release points); Activated sludge press; Cattle yards; Aerated wastewater ponds; Primary wastewater solids screen. The emission rates from the cattle truck and ambient cattle yard samples cannot be calculated, as the volumetric flowrates cannot be determined. Analysis of the biofilter inlet and outlet odour emission rates indicates that it is probably under-performing, thus releasing more untreated odour that expected. This has implications for the modelling exercise in the pilot study, in that the biofilter outlet clearly has the highest odour emission rate of any source. The overall impact of these sources at receptor locations near the IMPP has been determined with dispersion modelling, as presented in Section 6.

Table 4: Odour sampling results for pilot study

Sample location	Odour concentration	Specific odour emission rate	Odour emission rate
Biofilter inlet (point sample)	2,680 OU	N/A	56,220 OU/s
Biofilter outlet (point sample)	710 OU	N/A	16,460 OU/s
Cattle yards (isolation chamber sample)	790 OU	0.53 $OU/m^2/s$	840 OU/s
Cattle yards (ambient sample)	85 OU	N/A	N/A
Cattle truck (ambient sample)	1,805 OU	N/A	N/A
Primary wastewater solids screen (isolation chamber sample)	775 OU	0.52 $OU/m^2/s$	2 OU/s
Aerated wastewater pond (isolation chamber sample)	75 OU	0.05 $OU/m^2/s$	20 OU/s
Activated sludge press (ambient sample)	110 OU	N/A	4,245 OU/s

An odour sample cannot be analysed for odour intensity if the odour concentration is less than 100 OU due to limitations in the olfactometry equipment (for EnvironOdour equipment). Thus, the aerated wastewater ponds and ambient cattle yard samples could not be used for odour intensity estimation. The OCI relationship for the two biofilter inlet results were combined to generate an overall OCI relationship for the biofilter inlet, and likewise the four biofilter outlet results were combined to give an overall OCI relationship for the biofilter outlet. Odour intensity results are presented in Table 5. The critical odour concentration (COC_D) is determined from the OCI relationship, and represents the odour concentration corresponding to an odour intensity of 3, or 'distinct'. A higher COC_D value indicates that ambient concentrations of that source would be distinctly recognisable at a higher ground level odour concentration, and generally indicates a source that is not considered to be as problematic for community odour annoyance as a source with a low COC_D.

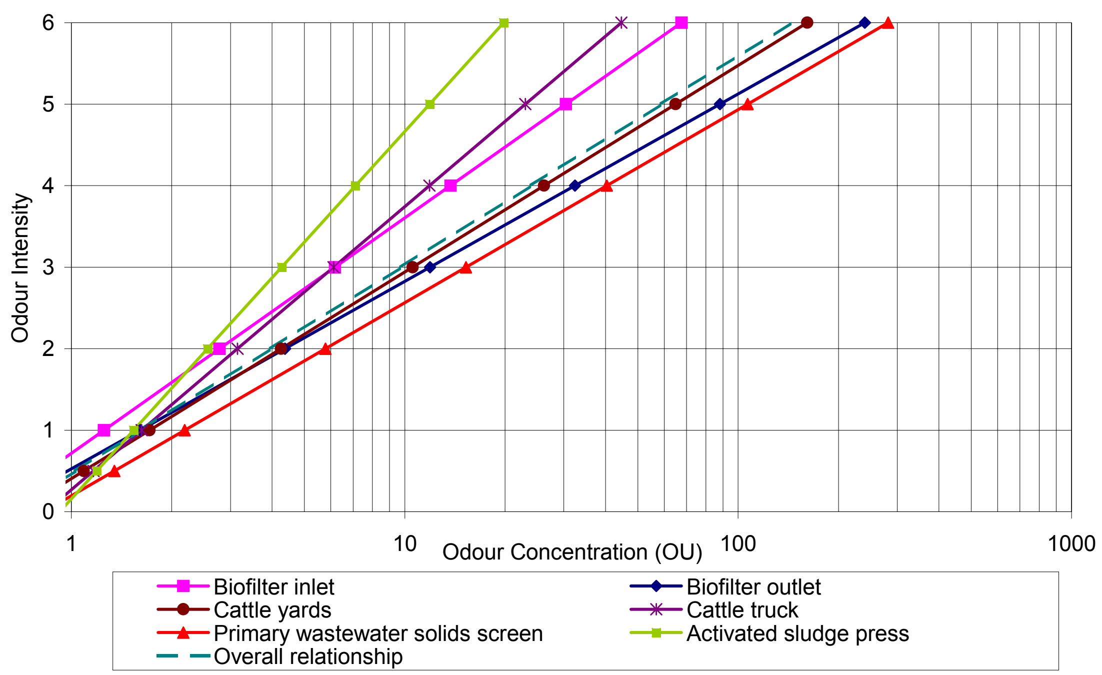
Table 5: Odour intensity results for pilot study

Sample location	Odour concentration (OC) - intensity (I) relationship [a]	r^2 [b]	COC_D (OU)
Biofilter inlet	I = 2.881 log(OC) + 0.717	0.833	6.2 OU
Biofilter outlet	I = 2.301 log(OC) + 0.525	0.839	11.9 OU
Cattle yards (isolation chamber sample)	I = 2.531 log(OC) + 0.405	0.960	10.6 OU
Cattle truck (ambient sample)	I = 3.479 log(OC) + 0.268	0.943	6.1 OU
Primary wastewater solids screen	I = 2.368 log(OC) + 0.195	0.845	15.3 OU
Activated sludge press	I = 4.486 log(OC) + 0.158	0.850	4.3 OU

Note [a] Converted from natural log (ln) in Appendix 3 to base-10 log for consistency with other measurements
[b] Indicates agreement of data to fitted curve, r^2 of 1 is a perfect fit

Figure 1 illustrates the differences in the OCI relationships for each group of sources tested during the pilot study. The activated sludge press is the most potentially annoying odour source of those tested. The figure also illustrates how the biofilter alters the characteristic of the rendering process odour, changing it from one of the more annoying odour sources to a relatively tolerable odour.

Figure 1: Odour concentration - intensity relationships for each source group for pilot study



The sources that smell strongly on-site, such as the cattle truck and activated sludge press, are characterised by low COC_D values (implying a stronger odour). Conversely, the biofilter outlet gives a high COC_D and is also observed to have a low odour impact on-site. The primary wastewater solids screen was separating mainly paunch material from the wastewater stream at the time of sampling, resulting in a relatively high COC_D. When this process is dealing with more degradable by-products, such as fats or blood, this source may show quite different results.

From evaluation of odour intensity for each source, they would be ranked in decreasing order of importance for odour emissions as follows: Activated sludge press; Cattle truck; Cattle yards; Biofilter outlet and Primary wastewater solids screen. Note that since the odour intensity – concentration relationship of the aerated wastewater ponds could not be determined, it is unclear how important these sources would be in ranking of odour emissions by intensity.

From the results of the pilot study, an overall OCI relationship has been derived (excluding the biofilter inlet). Since this combines sources of dissimilar nature (such as the biofilter outlet, which is a relatively tolerable odour compared to the activated sludge press), the overall OCI relationship is to be used only for comparison of the different possible analysis techniques. The derivation of the overall OCI assumed equal weighting of odour emissions from each source on site. The relationship for all sources combined (except the biofilter inlet) is $I = 2.564 \log_{10} (OC) + 0.4703$, which gives an overall COC_D of 9.7 OU.

Comparing these odour intensity results to Table 3 would imply that the cattle truck and activated sludge press have similar odour strength to other agricultural industries such as piggeries and dairy farms, and slightly stronger than poultry farms. However, the overall odour emissions from a rendering plant indicate that the rendering odours are not as strong as piggeries, poultry farms, dairy farms or landfills. The results also show that the measurements previously noted in MLA (2003) for rendering odour were a stronger odour than the untreated rendering air (biofilter inlet) from this pilot study. These differences in otherwise similar rendering odour sources (albeit from different plants) indicate the need for more extensive testing from multiple IMPP sites.

The overall odour impact of the facility must be assessed by considering both the odour concentration and odour intensity of the individual sources, and the combined effect of odour sources. These results are presented in Section 6.

5.4 Discussion of results

The specific odour emission rates that were measured for the aerated wastewater ponds and the cattle yards show quite different results to previous studies at the same plant. The aerated wastewater pond emission rate results were 20 times smaller than studies conducted in 2001 (also using the Australian Standard method), while the cattle yard measurements were up to 15 times lower than measurements from 2001. These differences are thought to arise in part due to the use of an isolation chamber, rather than a wind tunnel to measure the odour emission rate. Many studies have found that odour emission rates are dependent on the device used to collect the odour as well as the odour-free air flowrates used (APL, 2003), thus introducing an uncertainty into the results that cannot be quantified.

The odour concentration measurements on the biofilter outlet were of a similar magnitude to previous measurements on the same units. The emissions from the primary wastewater solids screen are substantially lower than previous measurements for the same location. This part of the wastewater treatment process is highly dependent on what is being processed in the rendering plant (e.g. the proportion of blood, paunch material and fatty material) in the wastewater stream. The samples were taken while mainly fresh paunch material was collected on the screen, resulting in a relatively low odour emission rate and high COC_D for this source. Further sampling would be required to establish whether this is sample is representative of this part of the process. The activated sludge press was not measured on previous occasions, however its odour emission rate appears reasonable.

The odour sources that have been measured in the pilot study can be ranked in order of importance for either the odour concentration or odour intensity, as presented in Table 6. The overall rank for off-site impacts was determined on the basis of the dispersion modelling results. These results assume that a peak-to-mean ratio of 2.3 is appropriate for all the sources modelled (volume sources and wake-affected point sources); these results would change if the biofilter stacks were not wake-affected.

Table 6: Ranking of sources for pilot study based on emissions and dispersion modelling

Source	Rank for odour concentration, based on emissions	Rank for odour intensity, based on emissions	Overall rank for off-site impacts, based on dispersion modelling
Biofilter outlet	1	3	1
Activated sludge press	2	1	2
Cattle stockyards	3	2	3
Primary wastewater solids screen	4	4	4

The addition of odour intensity data in an evaluation of odour emissions from an IMPP thus can provide a different perspective on the sources that are most critical to off-site impacts. In this case study, the biofilter generates the most odour, which also results in it being the primary source of off-site odour impacts.

Limitations in the olfactometry equipment mean that the OCI relationship for some sources cannot be determined. For the aerated wastewater ponds, the low emission rate was confirmed at the site by simply sniffing the air downwind of the ponds (qualitative observations). The odour was very weak to weak even at the edge of the pond, hence any odour released from the pond would be undetectable off-site once it is diluted further. Other IMPP that use different wastewater treatment techniques may not have such low odour emissions from the ponds, indicating the need for a more comprehensive database of odour emissions from a range of IMPP.

The choice of measurement technique can also dramatically affect the results obtained. For example, the cattle yard emissions were sampled in two ways (composite ambient sample and isolation chamber), with the cattle truck also sampled by a point sample. These gave quite different odour concentrations. In addition, the cattle yard and cattle truck samples had very different OCI relationships (COC_D of 10.6 or 6.1 respectively). The cattle yard relationship has been used in the modelling study.

Odour intensity has a pertinent application in selecting sources that would most benefit from emission control. For this study, the high odour emission and corresponding ground-level odour concentration shows that the biofilter is the dominant odour source. This has in turn resulted in the biofilter contributing the most to the odour intensity from the site.

6.0 Pilot odour intensity dispersion modelling study

6.1 Initial evaluation of distance to odour annoyance

If measurements are available of odour concentrations, intensity and volume flow rates from various sources within an IMPP, the information can be used in various ways. A common approach in many air quality areas is to undertake a multi-tier assessment that provides answers to various types of questions:

- A first tier screening approach useful in determining the scale of any problem and may rely on fairly simple treatments of the overall characteristics of a plant to determine, for example, the distance at which odour annoyance or complaints are likely from the overall operations.

- The second tier may well look at the detailed characteristics of the individual sources and use semi-empirical methods of determining annoyance characteristics without the necessity to undertake comprehensive emission, meteorological and dispersion modelling. Such second-tier systems can give a rapid appreciation of the likely interaction of the different odour characteristics in order to prioritise those sources and issues that are most likely giving rise to odour nuisance at nearby residences.

- A third level of investigation is often required for detailed design work and environmental impact assessments when the most detailed information on odour characteristics is used in conjunction with similar detailed descriptions of plant layout, site meteorology, community characteristics etc. to perform comprehensive modelling of each important odour source and determine such measures as odour exposure characteristics due either to individual sources or cumulative impacts (e.g. the likely response of community members when being exposed to the full range of likely odours from the IMPP over a long time period).

For the first two tiers of assessment, semi-empirical relationships between odour response, odour emission rates and source characteristics can be used. Williams and Thompson (1986) in summarising British work on “The effects of weather on odour dispersion from livestock buildings and from fields” gave a theoretical underpinning to a simple one line formula relating the distance d_{max} from the source within which odour complaints are likely to the odour emission rate of the source. This approach has been adopted by the UK Environment Agency (2002b) as an appropriate screening methodology.

This methodology proceeds as follows:

a) An assumption is made that odour annoyance due to a given source occurs when the odour level is a factor S times the odour level necessary to cause detection. Obviously S will be different for different people so it is reasonable in the first instance to choose a mean value for S (the original paper takes S in the range 5-10). With information at hand on odour intensity (and preferably hedonic tone) the parameter S (which can be thought of as an annoyance potential) could readily be defined for each source type.

b) For a given downwind location and odour source, the instantaneous odour concentration can be related to the value of S, the emission rate E of odour from a source, the peak-to-mean ratio R (to handle the premise that short-term odour concentrations are likely to cause annoyance), the windspeed and the vertical and horizontal turbulence parameters for the atmosphere at the time under consideration.

c) With reasonable values for the parameterisation of the dispersion components, it can be readily shown that the distance at which some form of odour response is likely to take place depends on the ratio of emission rate to annoyance potential S, raised to a power (0.5 - 0.6 is readily justified). This distance is also dependent on atmospheric stability and the source structure via the peak-to-mean ratio R.

For a variety of sources, it is therefore relatively straightforward to draw up a table of odour emission rates E, peak-to-mean ratios R, annoyance potential S and then determine the downwind distances at which odour annoyance or complaints are likely to occur.

The value of S can be estimated to some degree from the OCI curves. If it is assumed that the average person will respond to an odour concentration causing an intensity **I** = 2 or **I** = 3 (weak or distinct odour), then the factor S relating annoyance to detection can be readily determined.

Table 7 shows the relevant factors for the pilot field study undertaken for this project, together with the likely distances to annoyance (D_{max}, in m) for typical conditions of windspeed of 3 m/s and neutral atmospheric conditions, or for stable conditions with a wind speed of 1 m/s. Stable atmospheric conditions usually occur at night with low wind speeds and limited mixing of the plume, and can result in high odour impacts due to low-level odour releases. Neutral conditions describe typical daytime conditions with moderate winds and good mixing of odour emissions. Results from the MLA study "Determination of meat industry odour thresholds" (MLA, 2003) have also been included as Table 8 as a comparison for other rendering sources, using estimates of the appropriate peak-to-mean ratio and annoyance concentration for each source. The distance D_{max} clearly illustrates the large distances needed to avoid nuisance during stable conditions (such as calm night and early morning conditions). The use of this screening assessment approach also confirms the necessity for more detailed assessment at IMPP, as odour may be detected at distances of over 1000 m during adverse conditions. This also gives a good relative impact parameter for determining the relative importance of the various source types at a given receptor. For example, Table 7 shows that the biofilter is the most important for impacts, but the sludge press is also significant despite the 11-fold difference in emission rates. Hence, evaluation of emission rates alone gives quite a different conclusion to the use of odour intensity.

Table 7: Estimated distance (D_{max}, in m) to complaints for pilot study

Source	Peak-to-mean ratio	Annoyance concentration (COC_D, OU)	Emission rate (OU/s)	D_{max} for neutral conditions, 3 m/s winds	D_{max} for stable conditions, 1 m/s winds
Biofilter outlet	2.3	11.9	16,000	795	5,150
Cattle yard (isolation chamber)	2.3	10.6	840	145	945
Sludge press	2.3	4.3	1,415	345	2,225
Solids screening	2.3	15.3	2	5	20

Table 8: Estimated distance (D_{max}, in m) to complaints for odour emission data in MLA (2003)

Source	Peak-to-mean ratio	Annoyance concentration (COC_D, OU)	Emission rate (OU/s)	D_{max} for neutral conditions, 3 m/s winds	D_{max} for stable conditions, 1 m/s winds
Plant 1					
Boiler	10	5	570	435	2,830
Biofilter	2	10	149,850	3,110	20,140
Dispersion stack 1	10	20	418,600	2,495 [1]	16,160
Dispersion stack 2	10	20	481,600	2,715 [1]	17,575
Plant 2					
Rendering building	2	5	109,000	3,895	25,215
DAF	2	15	29,615	920	5,970
Contrashear	2	5	18,000	1,320	8,560
Cyclone	2	10	863	140	910
Tallow building	2	5	63,000	2,800	18,150
Plant 3					
Rendering	2	5	4,600	585	3,775
Biofilter	2	10	25,900	1,085	7,025
WW receival pit	2	5	7,161	760	4,925
Holding pens - kill floor	2	6	38,050	1,855	12,020
Holding pens - main	2	6	2,500	360	2,345

Note [1] Corrected to account for stack dispersion

6.2 Modelling methodology

The Ausplume model (version 5.4) has been used to model emissions from the biofilter outlet, cattle yards, primary waste-water solids screen and the activated sludge press. Each source has been modelled individually in Ausplume, so that the source-specific odour concentration – intensity relationship could be applied to the predicted concentrations for each source.

A sample meteorological data file for Melbourne that is provided with the Ausplume software (Melbourn.met, containing 8760 hours of data) was used, with no terrain. The hourly results predicted by the model were used in all analyses. A corresponding peak 1-second (nose response time) odour concentration was calculated from 1-hour average concentrations using a peak-to-mean factor of 2.3 as outlined in the NSW DEC draft odour policy (2001) for volume sources and wake affected point sources.

A polar receptor grid with spacing from 200m to 2000m, and 16 sectors was used in the modelling. The results were analysed in several ways for each distance from the source, and for both the 1-hour average and peak 1-second results:

- Calculation of odour concentration due to all sources combined, assuming odour concentrations are additive;
- Calculation of the highest odour concentration due to any of the sources;
- Calculation of an equivalent odour intensity due to each source individually, then adding the resultant odour intensity results;
- Calculation of odour intensity for each source individually, and calculation of highest odour intensity due to any of the sources.
- Calculation of odour intensity for all sources combined, using the overall OCI relationship derived in Section 5.3.

- Calculation of "odour hours" for odour intensity exceeding 2 or 3 for the total odour intensity results, or for the highest odour intensity due to any of the sources.

Odour guidelines from the various states, as outlined in Section 3.3, were used to evaluate the odour concentration results. The guidelines for Queensland and Tasmania are based on the 99.5th percentile, 1-hour average, while the Victorian, South Australian and Western Australian guidelines use the 99.9th percentile 3-minute average concentration. WA also uses a 99.5th percentile 3-minute average. Compliance with NSW criteria were calculated based on the nose-response-time 99th percentile concentration.

The frequency of detecting odour annoyance was used as an alternative method of assessment, by estimating the number of "odour hours" due to the site operations. For this project, the odour hour was calculated as the number of hours for which the odour intensity exceeds either 2 (weak) or 3 (distinct). These descriptors are commonly used in setting odour criteria based on odour intensity. The frequency of odour hours that is acceptable for residential areas is usually considered to be the 99.5th percentile (44 hours in the year).

6.3 Analysis of results

The dispersion modelling results for odour concentration, and the odour intensity calculated from these results are provided in detail in Appendix 4. The study focuses on whether intensity can be used to replace odour concentration criteria in determining odour impacts from a site, so the distance at which the odour concentrations are predicted to comply with the various odour guidelines is presented in Table 9. These results show that the stringent guidelines used in QLD, VIC, WA and TAS are quite hard to meet, requiring distances from 1360 to 3620 m away from the source. By contrast, the population-dependent criteria used by SA and NSW gave similar results and are achieved at distances of 830 to 990m (for individual residences).

Table 9. Distance from source for compliance with various odour concentration guidelines for each method of analysing the results

Odour guideline	Distance from source to compliance with odour concentration guideline			
	Total 1-hour average odour concentration from all sources	**Highest 1-hour average odour concentration from any of the sources**	**Total peak 1-second odour concentration from all sources**	**Highest peak 1-second odour concentration from any of the sources**
QLD guideline	1450 m	1360 m	N/A	N/A
VIC guideline [1]	3620 m	3450 m	N/A	N/A
WA guideline [1]	1490 – 2150 m	1390 – 1960 m	N/A	N/A
SA guideline [1]	890 [2] – 2500 [3] m, dependent on population density	830 [2] – 2280 [3] m, dependent on population density	N/A	N/A
TAS guideline	1700 m	1500 m	N/A	N/A
NSW guideline	N/A	N/A	990 [2] – 2360 [3] m, dependent on population density	940 [2] – 2140 [3] m, dependent on population density

Note [1] Converted from equivalent 3-minute guideline

[2] Applicable for single residence

[3] Applicable for urban areas or sensitive land uses

The odour intensity results that are detailed in Appendix 4 have also been assessed by evaluating the distance at which the 'weak' or 'distinct' odour intensity results are met, for the 99.5th percentile. These results are presented in Table 10, and indicate that the commonly-used descriptor of 'distinct' might be achieved at 450 m for a single source, but increases to 490 m for multiple sources for 1-hour average data. If the odour intensity were applied to peak 1-second data, these distances are shown to almost double and give similar numbers to the NSW concentration criteria. The odour intensity criteria of 'weak' is much harder to meet, requiring distances of 910 m for the 1-hour average data.

The use of an overall OCI relationship that includes all sources on the site shows higher results compared to the use of the total odour intensity, calculated with individual OCI relationships. The difference is particularly important for an odour intensity of 'distinct', however the overall odour intensity relationship (using COC_D = 9.7) can be used as an initial analysis of the odour intensity impacts from a source such as a meat processing plant that has several dissimilar types of odour. A more refined analysis could then be conducted using the individual relationships.

Table 10. Distance from source for compliance with odour intensity of weak or distinct for 99.5th percentile, for each method of analysing the results

Distance from source to compliance with odour intensity	Total 1-hour average odour intensity from all sources	Highest 1-hour average odour intensity from any of the sources	Total 1-hour average odour intensity using overall relationship	Total peak 1-second odour intensity from all sources	Highest peak 1-second odour intensity from any of the sources	Total peak 1-second odour intensity using overall relationship
Odour intensity of 'weak'	910 m	910 m	1040 m	1590 m	1590 m	1860 m
Odour intensity of 'distinct'	490 m	450 m	570 m	940 m	830 m	1000 m

Comparing the distance to compliance between Table 9 and Table 10, the odour intensity criteria are shown to give a smaller separation distance than the use of the odour concentration criteria. This is particularly the case when looking at an odour intensity of 'distinct', where 1-hour average intensity data gives separation distances of 450-570 m, compared to the odour concentration criteria that can be exceeded at more than 3000 m from the source.

The use of odour intensity as an alternative to odour concentration criteria shows promising application for IMPP. Sources with high odour emission rate, such as the biofilter in this study, dominate the predicted odour concentration impacts. Consideration of the low strength of this type of odour through the use of odour intensity thus gives a more realistic interpretation of the actual odour impact due to the IMPP at downwind receptor locations. This is evident in comparing the highest 1-hour average intensity results, that would require a distance of 450 m from the site to satisfy the odour criteria of 'distinct', to the 1-hour average concentration data that would indicate that receptors should be 830 – 3450 m from the source to satisfy the various state odour criteria. Thus, for a facility that may find meeting odour concentration guidelines problematic at nearby residences, odour intensity should be applied to determine the likelihood of odour annoyance for either a weak or distinct odour intensity.

Direct comparison of the pilot study results with the Queensland or WA odour intensity guidelines is only possible when considering the overall OCI relationship, as these guidelines do not allow for assessment of multiple, dissimilar sources. The use of odour intensity in the Queensland odour guideline requires application of a default peak-to-mean factor of 0.5 to the critical odour concentration calculated from the OCI. The results using the peak 1-second odour intensity and the Queensland odour concentration guideline are thus comparable.

Table 10 also shows that the assumption about what averaging period is appropriate for the OCI relationship is very important. It makes sense that the averaging period is of very short duration, probably closer to 1-second, than 3-minute or 1-hour due to the method of determining intensity that requires panellists to sniff the air. Hence, the impact distances based on the peak 1-second data in Table 10 are more likely to be realistic than those derived from 1-hour average data.

7.0 Recommendations for using odour intensity measurements

This study on the use of odour intensity in assessing odour impacts from the meat processing industry should be viewed as the first step towards an integrated industry approach to quantifying odour emissions, identifying OCI relationships, assessment of impacts and setting industry-specific odour guidelines that are applicable nation-wide. To fully achieve the goals of this approach, the following items need to be addressed:

- Generation of a representative database for odour emissions from IMPP.
- Further studies to consolidate the odour concentration – intensity relationships for the more odorous sources at an IMPP.
- Further work to establish a methodology for combining odour intensity results from unlike sources for use in assessment. This should be supplemented with field intensity measurements of odour surveys and analysis of odour complaints.
- Sensitivity analysis to identify the critical parameters for each facility, and possible use of a risk assessment approach.
- Derivation of an industry-specific odour guideline that can be used throughout Australia, and takes into account the relative importance of the different odour sources at an IMPP to the overall odour impact in the community.
- Formalising an industry-specific odour assessment procedure to incorporate all the above factors.

The adoption of odour intensity-based guidelines in each State and Territory of Australia may take time. Western Australia and Queensland have already adopted odour intensity into their odour guidelines. The other jurisdictions would need to be consulted to find out their willingness to use the alternative odour intensity-based criteria. Thus, national use of odour intensity may take some time to achieve but, since it can provide a more realistic odour assessment for a site with diverse sources and types of odour, it should be considered as a viable alternative for odour assessment.

In considering odour intensity for an alternative guideline for odour impacts, the measurement methodology needs to be standardised. Until an Australian method is standardised, the VDI 3882 method should be adopted, in conjunction with the Australian Standard method for odour concentration by dynamic olfactometry.

The results presented for this pilot study are intended to provide an initial evaluation of how odour intensity can be used for the meat processing industry. All of the sources presented here would have quite variable odour emissions, depending on the processes in the meatworks and also environmental conditions. Further studies are recommended to build up a suitable database of odour concentration and intensity data from a range of IMPP, so that the relationships are robust for use in regulatory applications.

A further matter for consideration is comparison between different laboratories. The scope of this pilot study did not allow for duplicate samples to be analysed by multiple laboratories, however this is recommended for future studies.

Odour intensity needs to be quantified better before application to integrated meat processing plants. More work is needed to identify appropriate OCI relationships to apply to this industry, for measurements at a range of plants and a variety of odour sources. A comprehensive database of odour emissions and corresponding OCI relationships for the type of sources typically found on IMPP is required, and the measurements conducted for this study can contribute to these data.

The use of odour intensity for odour regulation, as an alternative to the use of odour concentration, would be beneficial for the meat processing industry. This allows a more realistic assessment of the odorous sources that contribute to off-site impacts, so that a representative assessment can be made. If source reduction is required, odour intensity assists in identifying problematic sources that would achieve the most benefit for reduction in off-site impacts.

Odour intensity can be advantageously used to generate an industry-specific odour concentration criteria that to standardise odour assessments across Australia. This will ensure that the amenity of nearby surrounding land uses are protected, while not placing an onerous requirement for odour reduction on the industry.

8.0 Conclusions

Odour intensity could be a beneficial addition to odour assessments at integrated meat processing plants. However, current approaches are not sufficiently developed to allow odour intensity to be used to its fullest potential. Additional research work and policy development is required from all stakeholders for this promising approach to develop into a useful tool:

- Regulators: Need to more fully define procedures and expectations for odour assessments with intensity, particularly in relation to its application to industries with multiple diverse sources;

- Odour practitioners: Need to develop standards for analysis to allow intensity to be measured reliably and with confidence; and

- Industry: Needs to understand better the odour sources that they manage and the relationship between odour intensity and concentration from those sources.

This study has identified the following major conclusions:

- Currently, Australian state jurisdictions use odour concentration criteria as the basis of odour impact assessment. These concentration criteria treat all odours as having the same potential for impact and ignore the fact that some odours can be evident off-site whilst others, of equal concentration, are not evident. The offensiveness of the odour is essentially ignored.

- Western Australia and Queensland also allow development of alternative odour concentration criteria based on odour intensity of either weak or distinct. As with conventional concentration criteria, the averaging time, percentile compliance and measurement method are as important as the threshold to define the conservatism of an assessment.

- The interpretation of odour intensity results from multiple, dissimilar sources needs further work before it can be applied to the meat processing industry. This pilot study presents some possible methods to combine odour intensity relationships.

- Odour intensity is most commonly determined using VDI 3882.1 with modifications in association with AS/NZS 4323.3 (2001). Australian practitioners need to come to an agreement on the modifications that are appropriate and acceptable, to develop a standard method for odour intensity.

- Field observations of odour intensity show promise to provide a credible basis for odour regulations, for calibrating dispersion models and to assist in routine assessment of plant performance.

- The Weber-Fechner and Stevens Laws are most commonly applied to odour intensity-concentration relationships. The Weber-Fechner law has been used because it is simple and easy to derive parameters from literature data.

- The gradient of the odour concentration - intensity relationship for a particular source is a useful measure of the relative importance of the odour. In the Weber-Fechner relationship, a source with a large gradient is more likely to be evident at a particular distance than a source with a smaller gradient.

- The critical odour concentration is a useful measure of the importance of an odour for off-site impacts. The COC_D is the odour concentration that corresponds to distinct on the intensity scale. A higher COC_D means that a source is of relatively lower importance for off-site impacts.

- Strongest odours are from the sludge press and cattle truck sources, but relatively weak odours are found from the primary wastewater screen.

- The activated sludge press was found to be the source with the highest potential for impact based on its OCI relationship. The critical odour concentration was 4.3 OU.

- The method of odour measurement from surface sources to determine OCI relationships needs to be clearly defined. The results from the isolation chamber and flux hood methods gave quite different odour emission rates and OCI relationships for the cattle storage areas.

- The odour concentration - intensity measurements show that, not only has the biofilter reduced the concentration of the rendering plant odour but also has reduced the importance of the odours for off-site impacts. Comparing the biofilter inlet and outlet shows that the biofilter increases the COC_D of the rendering plant odour from 6.2 OU (second worst source) to 11.9 OU.

- Odour intensity-concentration relationships provide a more realistic determination of the importance of odour sources for off-site impacts.

- Odour intensity measurements can be used to determine whether predicted ground-level concentrations are likely to be evident off-site.

- The pilot study results show that the biofilter dominates the odour concentration results, and exaggerates the separation distance required between the source and receptors for the odour guidelines to be achieved. Including odour intensity in the analysis reduces the required separation distance to a more reasonable value.

- The use of odour intensity methods to set ambient odour criteria shows promising application to IMPP. Sources with a high odour emission rate, but low odour intensity can be evaluated more realistically using odour criteria based on intensity.

- Further work for IMPP needs to consider OCI relationships for other IMPP sites and a range of sources. Consideration of other dimensions of odour, such as hedonic tone or offensiveness, is important when fully evaluating the potential for off-site odour impacts.

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Appendix 1 Literature review of utility of odour intensity for agro-industrial sources

Issues with determination of odour intensity

Schulz 2002, 2003 and Pitt 2003 have debated the technical aspects of measuring and using odour intensity for odour assessments. Some of the more contentious aspects of this debate are as follows:

(i) Is the presentation sequence important and can it influence the outcome of odour intensity measurements?

Pitt suggests that presenting odour samples to panellists in ascending order can influence the outcome of the odour intensity measurement and recommends presentation in random order. Schulz argues that experience in the laboratory on one sample shows that presentation in ascending order compared with random order produced a results within 10 % at intensity score of 3. The time taken to do the random presentation was more than twice that taken to do the ascending order presentation due to additional cleaning of the olfactometer. This has implications for the cost of odour intensity sampling.

In the absence of a standard method for intensity and detailed comparative studies, the use of random presentation order is a 'no regrets' approach if the issues of practicality can be overcome. The odour intensity measurements undertaken for this project have been determined using random presentation, as the equipment cleaning issues have been overcome by EnvironOdour.

(ii) What does an odour intensity of 3 mean?

In VDI 3882.1, an odour intensity of 3 corresponds to 'distinct' but no further explanation is provided on how this descriptor should be understood by the panellist. Schulz's experience is that best panel performance is achieved through minimal coaching or training. The clarification that the intensity of 'distinct' is between intensities of 'weak' and 'strong' seems reasonable. EnvironOdour did not coach panellists on how on the definition of an odour intensity of 'distinct' for the measurements presented in this pilot study.

(iii) What panel size should be used for odour intensity measurements?

VDI 3882.1 states that the minimum panel size is eight persons. AS/NZS 4323.3 (2001) specifies a minimum panel size of four persons after retrospective screening, with six desirable (Schulz 2003). Larger panel size will result in higher cost of odour intensity measurements. No recommendation has been provided by Schulz or Pitt in relation to panel size.

For this study, EnvironOdour has used panel sizes of 6 to 8 persons, this is consistent with the requirements of AS/NZS 4323.3.

(iv) How is odour intensity calculated from panel responses?

Another issue that has been identified by Schulz and Pitt, but requires further definition here is the method of calculating the odour intensity. The method used by EnvironOdour for this study is detailed in Appendix 3 and is summarised below.

The VDI calculation method is an indirect method that correlates the odour intensity indexes with the dilution ratios. It is difficult to apply the method to different environmental samples. This also makes it difficult to apply the results in odour regulation. Clearly, the VDI method is used to determine how much reduction of an odour control measure is required to achieve the necessary reduction in odour sensation.

In the EnvironOdour study, a new calculation method (DynaScent method) was used to establish OCI relationships. The first step is to estimate the Presented Odour Concentration (POC) at the sniffing cup from its odour concentration. Then, the odour intensity indexes at the corresponding step are averaged. For each sample with six presentation steps in two rounds, a total of 12 points can be plotted on the chart. A log-linear regression line is then developed.

During the odour concentration measurement, all the panellists report certain and correct responses at the last dilution step. It is reasonable to assume that the panellists will report the odour intensity category of very weak at this step. Furthermore, the Australian Standard method estimates the odour threshold by taking the geometric mean of two dilution steps (at the smaller dilution step, the panellist confirms the detection with certain and at the larger dilution step, the panellist reports the non-detection). Therefore, the difference between odour threshold defined by the VDI and Australian standard is differed by a factor of 1.4 or the square root of the dilution factor (Dravniek's method). At any dilution step i, the presented odour concentration at the sniffing cup (POC_i) is calculated by:

$POC_i = Z_{t,j} / Z_i = 1.414.OC/Z_i$, where Z_t is the threshold dilution ratio, Z_i is the dilution ratio, OC is the odour concentration.

The method used in this study correlates odour intensity with the Presented Odour Concentrations (POC) at the sniffing cup. This direct method normalises the different initial odour concentration. The same odour type from many samples can now be plotted on the same chart that results in a single correlation line. The approach includes a large sample size to generate results that are more reliable. Once the OCI relationship is established, the critical odour concentration (COC_D, the presented odour concentration corresponding to an odour intensity level of 'distinct') can be calculated.

(v) What does the odour intensity at an odour concentration equivalent to 1 OU denote and should the odour intensity at this concentration be equal to 0.5?

An odour unit is by definition the threshold of odour detection for 50% of the panellists. Thus, at the detection level, an intensity between 'not perceptible' and 'very weak' should be obtained. However, there is considerable ongoing debate on this issue which needs to be resolved prior to developing a standard method for odour intensity measurement.

(vi) What does odour intensity measurement cost?

The cost of odour intensity measurements will depend on the laboratory undertaking the work, but clearly the cost will be driven by the requirements of the method and particularly those requirements that affect the equipment that can be used, the number of persons required to conduct the measurements and the time that is taken to conduct a measurement. Costs obtained for this study from four laboratories in NSW and Qld ranged from $490 to $730 per sample, for odour concentration and intensity analysis. A higher cost of $1080 is charged by one laboratory for the use of random presentation order (requiring cleaning between presentation steps) instead of ascending presentation order. The laboratory selected for this study always uses random presentation order.

Currently there is no standard method for odour intensity that is tailored to use the Australian Standard odour concentration measurement and so actual costs vary, and are not necessarily a good measure of quality or value for money. Standardisation will lead to better odour intensity measurements and lower costs in the long term by setting expectations for quality assurance and quality control and by providing laboratories with a framework to optimise equipment and innovate.

Examples of odour intensity measurements for agricultural industries

Wang and Feitz (2004) collected 134 odour concentration samples and 60 odour intensity samples from dairy farms in Victoria, NSW and Queensland. Based on relationship between odour concentration and odour intensity and dispersion modelling, an odour impact criterion of 6.5 OU (equal to the critical odour concentration), 1-hour average, 99.5th percentile was determined for sensitive receptors. There is no clear indication of whether the 1-hour averaging time is appropriate, however there will be substantial differences between 1-hour and 3-minute or 1-second averages (using nose-response time conversions, see NSW DEC 2001). Similarly, the percentile is critical with higher percentiles being driven by infrequently occurring meteorological events. Studies in the pig industry have shown that 98-99th percentiles may be better. Weber-Fechner model has been fitted to the data ($r^2 = 0.82$) and the critical odour concentration was found to be 6.5 OU. Samples were analysed using the Australian Standard method (2001) and seven-point VDI intensity scale.

Schulz et al 2002 provides a summary of odour intensity vs. odour concentration plots for a number of industrial odour sources. A Weber-Fechner model has been fitted to the data and critical odour concentrations (for I=3) determined for each, these results are summarized in the following table. Equations have been determined from the figures presented. Samples were analysed using the Australian Standard method for dynamic olfactometry (2001) and seven-point intensity scale from VDI 3882.1.

Odour source	**k_w**	**Constant**	**Reference**
Alumina Stack	2.95	0.71	Schultz et al 2002
Landfill (ambient)	1.89	2.43	Schultz et al 2002
Oil extraction plant stack	2.11	1.21	Schultz et al 2002
Steam stripper (woolscour WWTP)	2.51	2	Schultz et al 2002
Alumina refinery TO	1.39	1.11	Schultz et al 2002
Butanol	1.38	1.2	Schultz et al 2002

Appendix 2 Past results, experiences and problems in odour assessments for IMPP

Management of odour emissions from IMPP utilises various types of information on source and odour characteristics at different stages of the operation:

- In planning new facilities, an odour impact assessment is important both for satisfying environmental regulations and in designing, specifying and commissioning odour control measures in various parts of the plant.

- Established facilities often require detailed odour information when undertaking expansions and/or reacting to the increasing likelihood of a community encroaching into what was previously an "effective buffer zone".

- The investigations of complaints about odour and dust amenity require a good understanding of not just the dispersion and emission modelling undertaken in the above studies but also the types of operating, environmental and socio-economic conditions under which odour annoyance can lead to complaints.

- Regular environmental performance monitoring for various parts of the plant requires a good knowledge of variability of odour impacts likely from day-to-day operations of IMPP.

Special characteristics of IMPP odour sources

In many ways, IMPPs have a much more difficult task in undertaking comprehensive odour assessments than many other agri-industries due to the following factors:

- Most IMPP have a variety of source structures, for instance, sources that range from short to medium-term stacks for combustion and odour control devices, and relatively small ground-level sources at various parts of the primary waste water treatment through to extensive ponds and other types of surface area sources such as cattle yards. The source structure can have a significant influence on the dispersive abilities of the atmosphere and the role of fluctuating odour concentrations in causing odour annoyance. Consequently, the peak-to-mean ratios used in estimating short-term (nose response time) odour concentrations from predictions of hourly averages can vary from values of 1.5 - 30, depending on source structure, downwind distance and atmospheric conditions.

- There are likely to be significant variations in the degree of offensiveness of odour from different sources in IMPP, both due to the different types of volatile compounds emitted in the various processes and also the community perception of such odours.

- As for noise assessments, it is quite possible that removing the major source may reveal odour sources that may still cause significant annoyance. It is not clear at this stage whether the various odours from IMPP operations are likely to be additive, synergistic or antagonistic (i.e. odours from multiple sources may have a combined effect that is equal to, greater than or less than the sum of contributions).

- There is a variety of community responses to IMPP odour, due to the adverse nature of odour from different parts of the plant, from different plants and due to the social acceptability or otherwise of such industrial plants in various types of communities. For example, there are several instances of communities living quite happily within 100 m of major wastewater facilities whilst other communities close to even seemingly well-controlled facilities still experience significant annoyance.

- IMPP odour sources are likely to have strong temporal and spatial variability. For example, past MLA projects and other studies on sewage treatment plants have shown a strong variability in odour characteristics that can occur at various parts of the processing cycle. Anaerobic ponds are not homogeneous bodies of waste material and can have emission rates that vary considerably over the area of the pond and over time. Short-term sampling regimes are unlikely to encompass such strong variability.

- Increasingly, evidence points towards the absorption of odorous volatile compounds onto the various types of dust that occur in agricultural production facilities. IMPP stockyards are likely to produce significant components of dust on various occasions if not regularly washed down which may then enhance the total odour emissions from the plant.

All of the above factors suggest that careful consideration should be given to the various odour characteristics of the dominant sources. Odour concentration or intensity measurements are only likely to be part of the overall setting and it is probable that considerable progress will be made in the next 10 years with the advent of more automated monitoring and better appreciation of the various factors involved in being able to define more carefully and practically the main factors in each of the above issues.

Control devices and measures

IMPPs, especially in the past 10 years, have employed novel forms of odour control such as:

- Biofilters, scrubbers and UV-ozonators that aim to reduce the strength and offensiveness of the odour streams from the main sources within the plant. Whereas the attaining of large odour destruction efficiencies as promised in the literature (e.g. 90-95% for scrubbers and biofilters) may not be practically possible or sustainable, the change in odour characteristics (intensity) of the exhaust from these devices may be sufficiently great that such odour characteristics are an important part of plant specification, performance monitoring and acceptability by environmental agencies.

- IMPPs are implementing major new practices in wastewater treatment requiring considerable capital expenditure. The effectiveness from an odour control point of view is often not predictable either from past experience or pilot plant measurements.

- Animal storage facilities at IMPP may be either open, partially enclosed or fully ventilated by mechanical or natural means. The odour characteristics of such facilities depend very much on their mode of operation and cleaning procedures used.

- Many IMPPs have now instituted the separation of airstreams from different parts of the plant for use in different treatment technologies (for concentrated odour streams) or direct discharge to the atmosphere (for more diluted odours).

- The scheduling of activities such as cattle arrival and processing of various types of by-product material is increasingly important in overall operations and odour management.

Problems in odour assessment for IMPP

Odour monitoring and modelling as a science is in its infancy. Only in the past decade have relatively simple measurement techniques such as dynamic olfactometry become sufficiently standardised that different laboratories can give answers that agree within a factor of 2-5 of each other. There are no routine methods of measuring ambient odour concentrations although there is more experience being gained in the field measurements of odour intensity, for example. These and other technical problems are of particular concern to IMPP and lead to the following issues:

- Do odour concentrations or intensities from different sources become additive in producing a response in an odour-sensitive person?

- Why can there be high ambient odour concentrations measured or forecast but obtain no response from local residents?

- How strong and important is the variability between odour measurement laboratories, both for concentration and odour intensity measurements?

- Given that dispersion and meteorological prediction schemes are currently very poorly validated for odour dispersion, how valuable is it to include other odour characteristics in any odour impact assessment?

- The lack of uniformity in regulation and technical assessments between the different states in Australia causes a significant problem in either receiving approvals or giving encouragement to undertake R&D activity in odour control.

- There are currently no comprehensive studies of community responses to odour around IMPP, at least not in Australasia. It is unclear what relevance the various studies around similar sources in the United Kingdom and the Netherlands have to the Australasian environment.

- In Australia there is little use of on-site odour measurement techniques such as employed quite successfully in the United States waste water industry. Methods such as the “Nasal Ranger” (Stephenson et al 2004) enable a field observer to not only get an idea of odour concentrations and intensity but also give a fuller description of other odour characteristics. Such a device may also be useful in undertaking community assessments.

- There are at present no IMPP-specific odour intensity-based criteria, even though some states have regulations allowing for such proposals from the industry to be considered.

The above comments form the backdrop of the reasons why consideration of odour measures such as odour intensity may be one useful part of a reconsideration of the approach to odour evaluation for the IMPP industry.

Appendix 3 Pilot study odour measurement report

(Copy of report from EnvironOdour held by MLA)

Appendix 4 Pilot study odour modelling report

The odour concentration and intensity measurements for the pilot study were modelled for the biofilter outlet, cattle yards, primary wastewater solids screen and activated sludge press. Results for the biofilter inlet were not used as it is not an atmospheric release point. Measurements on the aerated wastewater ponds were too low to derive an odour concentration – intensity (OCI) relationship, and so have not been included. Odour emissions from other sources (e.g. combustion stack) are known to be relatively small from previous measurements and were not sampled for the pilot monitoring study.

A summary of the source emission rates and parameters used in the modelling is provided in Table A4.1.

Table A4.1 Source emission rates and source parameters used in dispersion modelling

Name	Odour emission rate	Source dimensions	Release height
Biofilter outlet (total of 4 release points)	16,000 OU/s	2.5 m by 2.5 m	5 m
Cattle yards	840 OU/s (0.53 OU/m²/s)	40 m by 40 m	5 m
Primary wastewater solids screen	2 OU/s (0.52 OU/m²/s)	2 m by 2 m	3 m
Activated sludge press	4,250 OU/s	3 m by 3 m	3 m

Dispersion modelling using Ausplume 5.4 and a met file for Melbourne was carried out to predict the odour concentration and odour intensity at a range of downwind distances, using the following alternative methods for both the 1-hour average and peak 1-second results:

- Calculation of odour concentration due to all sources combined, assuming concentrations are additive;
- Calculation of the highest odour concentration due to any of the sources;
- Calculation of an equivalent odour intensity due to each source individually, then adding the resultant odour intensity results;
- Calculation of odour intensity for each source individually, and calculation of highest odour intensity due to any of the sources.
- Calculation of odour intensity for all sources combined, using the overall OCI relationship derived in Section 5.3.
- Calculation of “odour hours” for odour intensity exceeding 2 or 3 for the total odour intensity results, or for the highest odour intensity due to any of the sources.

The predicted 1-hour average odour concentration results are presented in Table A4.2, while the peak 1-second odour concentrations are presented in Table A4.3. Three different percentile values are presented, for use with the odour concentration criteria that are used in different states.

Table A4.2 Total 1-hour average odour concentration for all sources and highest from any of the sources, at various distances from the plant

Distance from source (m)	Total 1-hour average odour concentration from all sources (OU)			Highest 1-hour average odour concentration from any of the sources (OU)		
	99.9th percentile	99.5th percentile	99th percentile	99.9th percentile	99.5th percentile	99th percentile
250	35.9	29.4	21.7	31.2	25.8	19.5
500	13.9	11.3	8.3	12.1	10.0	7.1
1000	5.1	4.1	2.9	4.4	3.7	2.5
1500	2.8	2.3	1.6	2.5	2.0	1.4
2000	1.9	1.5	1.1	1.6	1.3	0.9
2500	1.4	1.1	0.8	1.2	1.0	0.7
3000	1.1	0.9	0.6	0.9	0.8	0.5
QLD criterion		2.5			2.5	
VIC criterion	0.7			0.7		
WA criterion	2.9	1.4		2.9	1.4	
SA criterion	1.4 - 7.1			1.4 - 7.1		

Taking the WA criterion as a reasonable approach (see MLA report "Determination of meat industry odour thresholds", 2003 for a similar conclusion), the necessary buffer zone from concentration predictions is in the range 1500-2000 m. Based on the community reactions to this plant, this appears to be a factor of 4 larger than the distances at which complaints have been received in the past 2-3 years.

Table A4.3 Total peak 1-second odour concentration for all sources and highest from any of the sources, at various distances from the plant

Distance from source (m)	Total peak 1-second odour concentration from all sources (OU)			Highest peak 1-second odour concentration from any of the sources (OU)		
	99.9th percentile	99.5th percentile	99th percentile	99.9th percentile	99.5th percentile	99th percentile
250	82.5	67.7	49.9	71.8	59.4	45.0
500	32.0	25.9	19.1	27.8	23.0	16.3
1000	11.7	9.5	6.7	10.2	8.4	5.8
1500	6.5	5.3	3.7	5.7	4.7	3.3
2000	4.3	3.5	2.5	3.8	3.1	2.2
2500	3.2	2.6	1.8	2.8	2.3	1.6
3000	2.5	2.0	1.4	2.2	1.7	1.2
NSW criterion			2 - 7			2 - 7

For this site, the local community is in an urban setting and the relevant NSW criterion is for 2 OU. This would require a buffer zone of 2000-2500 m, again considerably higher than expected.

The predicted 1-hour odour intensity, using the individual OCI relationships for each source, are presented in Table A4.4. Odour intensity calculated from the peak 1-second concentration are presented in Table A4.5. Odour intensity has been calculated using an overall OCI relationship for all sources measured in the pilot study, and the results are presented in Table A4.6 for the 1-hour and peak 1-second results.

It would be expected that a reasonable criterion for annoyance would be for an intensity of 3 for an averaging time of 1-second to 3-minutes (there is debate on what exposure time is relevant for intensity measurements). Taking the 1-second exposures and the 99th percentile as the appropriate statistic, Table A4.5 suggests a buffer zone of around 800 m, a much more realistic value. An alternative approach would be to take the odour concentration equivalent of I = 3 for the average curve as requiring a 10 OU concentration criterion for a 1-second exposure. Table A4.3 then gives a similar value of around 800 m. Table A4.6 confirms that this is consistent.

Table A4.4 Total 1-hour average odour intensity for all sources and highest from any of the sources, at various distances from the plant

Distance from source (m)	Total 1-hour average odour intensity from all sources			Highest 1-hour average odour intensity from any of the sources		
	99.9th percentile	99.5th percentile	99th percentile	99.9th percentile	99.5th percentile	99th percentile
250	7.1	6.1	5.1	4.0	3.8	3.5
500	3.4	2.8	2.5	3.0	2.8	2.5
1000	2.0	1.8	1.5	2.0	1.8	1.5
1500	1.4	1.2	0.9	1.4	1.2	0.9
2000	1.0	0.8	0.0	1.0	0.8	0.0
2500	0.7	0.0	0.0	0.7	0.0	0.0
3000	0.0	0.0	0.0	0.0	0.0	0.0

Table A4.5 Total peak 1-second odour intensity for all sources and highest from any of the sources, at various distances from the plant

Distance from source (m)	Total peak 1-second odour intensity from all sources			Highest peak 1-second odour intensity from any of the sources		
	99.9th percentile	99.5th percentile	99th percentile	99.9th percentile	99.5th percentile	99th percentile
250	10.5	9.5	8.5	4.8	4.6	4.3
500	6.7	5.5	4.4	3.8	3.7	3.3
1000	2.8	2.7	2.3	2.8	2.7	2.3
1500	2.3	2.1	1.7	2.3	2.1	1.7
2000	1.9	1.7	1.3	1.9	1.7	1.3
2500	1.5	1.3	1.0	1.5	1.3	1.0
3000	1.3	1.1	0.7	1.3	1.1	0.7

Table A4.6 Total 1-hour and 1-second odour intensity using overall odour concentration - intensity relationship, at various distances from the plant

Distance from source (m)	Total 1-hour average overall odour intensity from all sources			Total peak 1-second overall odour intensity from all sources		
	99.9th percentile	99.5th percentile	99th percentile	99.9th percentile	99.5th percentile	99th percentile
250	4.5	4.2	3.9	5.4	5.2	4.8
500	3.4	3.2	2.8	4.3	4.1	3.8
1000	2.3	2.1	1.7	3.2	3.0	2.6
1500	1.6	1.4	1.0	2.6	2.3	1.9
2000	1.2	0.9	0.6	2.1	1.9	1.5
2500	0.8	0.6	0.0	1.8	1.5	1.1
3000	0.6	0.0	0.0	1.5	1.2	0.8

The number of odour hours that exceed an odour intensity threshold of either 2 (weak) or 3 (distinct) are presented in Table A4.7 for the 1-hour average data, while peak 1-second results are presented in Table A4.8 (using the individual OCI relationships for each source). Results calculated using the overall relationship for all sources are presented in Table A4.9. As expected, the results show a clear reduction in the number of odour hours as the distance from the source increases. Odour intensity results are often analysed using the 99.5th percentile result (corresponding to 44 hours per year) with an intensity of 3.

Using a peak 1-second odour intensity would result in a very different perception of the likelihood of odour annoyance than the 1-hour results. Further field observations and community surveys would be required to determine whether the 1-hour or 1-second data are more appropriate for community odour annoyance. Use of the overall OCI relationship gives different results to the use of individual relationships, however the results are adequate for an initial evaluation of the impacts.

Table A4.7 Number of odour hours exceeding 1-hour average odour intensity threshold for total of all sources or highest from any of the sources, at various distances from the plant

Distance from source (m)	Total 1-hour average odour intensity from all sources		Highest 1-hour average odour intensity from any of the sources	
	Number of hours with odour intensity over 2	Number of hours with odour intensity over 3	Number of hours with odour intensity over 2	Number of hours with odour intensity over 3
250	1363	420	1363	288
500	295	25	295	21
1000	21	0	21	0
1500	0	0	0	0
2000	0	0	0	0
2500	0	0	0	0
3000	0	0	0	0

Table A4.8 Number of odour hours exceeding peak 1-second odour intensity threshold for total of all sources or highest from any of the sources, at various distances from the plant

Distance from source (m)	Total peak 1-second odour intensity from all sources		Highest peak 1-second odour intensity from any of the sources	
	Number of hours with odour intensity over 2	Number of hours with odour intensity over 3	Number of hours with odour intensity over 2	Number of hours with odour intensity over 3
250	2849	1380	2849	1191
500	1164	243	1164	183
1000	175	0	175	0
1500	45	0	45	0
2000	0	0	0	0
2500	0	0	0	0
3000	0	0	0	0

Table A4.9 Number of odour hours exceeding 1-hour and peak 1-second odour intensity threshold based on overall odour concentration - intensity relationship for all sources, at various distances from the plant

Distance from source (m)	Total 1-hour average overall odour intensity from all sources		Total peak 1-second overall odour intensity from all sources	
	Number of hours with odour intensity over 2	Number of hours with odour intensity over 3	Number of hours with odour intensity over 2	Number of hours with odour intensity over 3
250	1687	631	3206	1596
500	538	54	1404	464
1000	45	0	335	39
1500	0	0	79	0
2000	0	0	25	0
2500	0	0	0	0
3000	0	0	0	0

Table A4.8 shows that 170 odour hours based on 1-second values will give a buffer zone of around 1100 m.