ENVIRONMENTAL STANDARDS FOR INDUSTRIAL ODOUR EFFECTS:

A Recommended Approach for New Zealand

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A Recommended Approach

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FOREWORD

The preparation of this document was originally instigated in response to proposed methods for assessing industrial odours within the Environment Waikato Consultative Draft Regional Plan[1]. Following its submission to that council, a consultation process was undertaken with council staff and air professionals throughout New Zealand and Australia. A result of this process has been some important revisions to the Proposed Regional Plan's Air Module, including the restriction of proposed modelling guidelines to new proposed activities and a more detailed discussion of alternative odour assessment techniques and their appropriate use.

Another result has been the development of this report into a more general guideline document for the management of industrial odour effects.

As well as identifying the limitations and advantages of existing odour management approaches, a process is recommended for the development of more effective odour modelling guidelines.

An underlying principal of industrial odour management policies for many industrialised countries is the common law requirement to not create odour nuisance. There are also specific environmental statutes, such as New Zealand's Resource Management Act 1991 (referred to herein as "the RMA"), that imposes a duty upon industry to avoid causing "objectionable" or "offensive" odours to such an extent that they are likely to have adverse environmental effects. It should be noted that in New Zealand, this duty in itself is not enforceable, but enforcement orders or abatement notices are issued for controlling such adverse effects.

The various regulatory tools that have been developed to enforce the "no objectionable or offensive odour effects" duty, rarely include any clear definitions or criteria for assessing at which point such effects are causing significant adverse effects on the environment. The reason for this, which is well understood, is that the definition of an objectionable or offensive odour effect is subjective. This in part explains the presence of odour assessment guidelines that generally entail a description of methods only for obtaining information (examples include odour surveys, diaries, and complaint records). The criteria for assessing information obtained so to establish whether or not adverse effects are occurring, is generally absent.

The exception to the above, is the specification of numeric odour modelling standards or guidelines for comparing to olfactometry/odour dispersion modelling concentration predictions. In effect these guidelines represent an attempt to objectively define the level of odour exposure when significant "objectionable" or "offensive" effects are likely to occur.

Olfactometry and dispersion modelling techniques combined with numeric odour guidelines promise to provide a consistent and systematic basis for assessing odour, particularly for proposed new activities. However, the development of concentration guidelines using laboratory-generated odour dose-response experiments combined with an "annoyance concentration threshold" model of human responses within the real environment is considered to be a major limitation to the olfactometry/modelling assessment approach.

For example the predicted location of the 99.5-percentile odour concentration contour for 10 ou/m^3 (1-hour average) is often dramatically different from that of the 99.9-percentile concentration at 2 ou/m^3. Correspondingly, the conclusions that could be drawn regarding to the acceptability of the predicted level of odour impact can be very different.

For confirmation that there is something seriously amiss with some proposed odour guidelines, one can compared the predicted locations of a 99.5-percentile concentration of 10 ou/m^3 with a 99.9-percentile concentration of 0.25 ou/m^3 from a stack source. Whereas the difference between 10 ou/m^3 and 2 ou/m^3 can be large, the difference between 10 ou/m^3 (99.5 percentile) and 0.25 ou/m^3 (99.9 percentile) is often extremely large. These latter two values represent the existing extremes of the current debate regarding an appropriate concentration standard or guideline for protecting the community from objectionable or offensive odours.

The reader should note that in practice, the terms standard and guideline often have similar implications when used in the context of allowable ambient odour concentration levels. The term standard is sometimes used to indicate statutory status. However, ambient concentration guidelines have in practice the effect of a standard, particularly when there are no overriding statutory standards and when the concentration guideline forms part of an official regulatory policy. In New Zealand this equates to a guideline being adopted as part of a Regional Plan.

One of the aims of this report is to review the evolution of odour concentration guidelines over the last ten years or more, with specific reference to the technical evidence supporting the approaches used. In recent times a number of odour management discussion documents have neglected such an analysis, tending to only provide general descriptions of assessment and monitoring methodologies, case law and references to the RMA.

This report is primarily a technical document, the aim of which is to provide a sound basis for developing effective regulatory practices for odour management by providing some practical guidance for community surveys and the appropriate role for olfactometry/dispersion modelling assessment methods. This will assist in the successful and consistent implementation of odour management practices.

The management of industrial odours has been a long-standing problem that can not be easily resolved. This report aims to clarify odour management issues with the ultimate goal of improved air quality management policies. It is important to note that the guidelines recommended in this report are aimed at providing greater certainty for companies who emit odour. It is not to provide protection for those industrial sites that do create an unreasonable level of odour impact.

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1 INTRODUCTION

A suite of standard regulatory tools is routinely listed in documents that deal with the subject of odour management [2,3]. These include the imposition of buffer distances, best practical option, compliance with industrial codes of practice, community surveys and compliance with modelled odour concentration guidelines. The avoidance of significant adverse effects due to objectionable or offensive odours is considered to equate to guarding the public against odour nuisance effects, the degradation of amenity values and potentially ill-health effects[4].

The use of odour concentration standards or guidelines for comparison with dispersion modelling results is an increasingly popular assessment tool that has been used in New Zealand and Australia. This has been driven by the development of reliable olfactometry methods for quantifying odours of industrial emissions[5,6], as well as the desire to obtain a more consistent odour assessment approach. Consequently, there has been a trend for some regulatory authorities to specify concentration guidelines in the same manner that percentile noise guidelines are specified for controlling adverse effects (eg. 55 dBA).

The 2.0 ou/m^3 (1-hour average) guideline for area sources was first used in New Zealand as a design target for the upgrade of the Mangere Sewage Treatment Plant, Manukau City operated by Watercare Services Ltd. This appears to have become the Auckland Regional Council (ARC) interim guideline for area sources[7]. The guideline is also similar to that adopted by the Southland Regional Council, which requires a maximum 3-minute odour concentration beyond the site boundary of 0.3 ou/m^3. The Canterbury Regional Council has also used similar guidelines when assessing air consent applications[8]. Finally, a Ministry for the Environment funded draft manual for control of wastewater treatment plant odours in New Zealand, also promotes the use of very similar odour concentration values to the ARC's interim odour guideline and that proposed by Environment Waikato[1]. It is considered that these guideline values that relate to area sources (normally wastewater treatment plants) are appropriate for proposed new activities that are close to sensitive urban areas.

However, there have been occasions of the above guidelines for area sources being applied to the assessment of resource consent applications for "existing" activities. This is likely to overstate the extent of adverse effects because the guidelines are conservative. Furthermore it does beg the question why such an approach is used in the first instance when the community response can be more directly assessed.

For stack sources the guideline can often be in the order of 0.25 ou/m^3 (1-hour average), as the assumed peak-to-mean ratios are so much higher. Even for the evaluation of new proposed activities such guidelines have the potential to stifle industrial development to unnecessary extent. Therefore the need for a robust alternative odour modelling guideline for stack sources is an important issue. The growing list of case studies for processes that have relatively consistent and continuous stack discharge characteristics, suggest that the 5 ou/m^3 divided by a peak-to-mean ratio type modelling guideline is overly conservative. This is to such an extent that the resultant guideline could have little practical use to either regulators or industry. The poor level of science supporting the rationale for developing such guidelines and the potential consequences is a serious issue that needs to be re-addressed.

It is clear that there needs to be a distinction between guidelines that may be used to evaluate new proposed activities that are near built-up urban areas and those that are existing, as the former can justifiably be more restrictive.

The original 1970s to early 1980s research used to develop historical odour concentration guidelines are discussed, as well as the subsequent advances in odour research and olfactometry methods. In particular it is necessary to consider how the deficiencies in past assumptions and methods have perpetuated through to more recent efforts to develop odour concentration guidelines in both Australia and New Zealand. The inclusion of Australian practices is particularly relevant, as the standards/guidelines being proposed by some Regional Councils and recommended by a number of experts within New Zealand, have been directly influenced by Australian approaches.

As well as highlighting the deficiencies in the methods being used to develop odour concentration guidelines, it is also important to offer alternative approaches. This report considers the wider odour management issues, including the process for developing community-based guidelines, and appropriate monitoring and assessment approaches.

A detailed discussion of odour control technologies and systems is not provided for two reasons. Firstly, this report is primarily concerned with the wider regulatory aspects of odour management, including effects monitoring and assessment criteria. Considerations of appropriate control technologies and mitigation measures that can be implemented would be more appropriately detailed within an operators guideline document, or code of practice that is specific to a particular industry type.

Secondly, it is considered that the majority of expertise regarding odour control technologies and BPO is specific to an industry type and is often held by individuals who have worked within a particular industry. Therefore to provide useful and practical advice on control technologies, such guidelines should ideally focus upon specific industrial sectors and include practical experiences of plant operators.

2 THE 1991 RESOURCE MANAGEMENT ACT

One of the key elements of the Resource Management Act, as stated in its purpose is to "avoid adverse effects of activities on the environment". Section 17 of the RMA expands on this and states that *"Every person has a duty to avoid, remedy, or mitigate any adverse effect on the environment arising from an activity…."*. This duty is only enforceable if an abatement notice, or an enforcement order is served or made to:

" Require a person to cease, or prohibit a person from commencing, anything that,……is or is likely to be noxious, dangerous, offensive or objectionable to such an extent that it is likely to have an adverse effect on the environment…" – Section 17(3)(a).

There has always been considerable debate regarding the definition of what is an objectionable or offensive odour, as air permits often require that such odours do not occur beyond a site boundary. Such conditions are generally in line with regional policies of air quality plans. However, section 17 (3)(a) would suggest that it is the likelihood of adverse effects being caused that is the primary consideration. Furthermore, so called objectionable or offensive odours can occur, as long as they are of an extent that is unlikely to cause adverse environmental effects.

Under the RMA it is necessary to determine whether or not an adverse effect has in fact occurred, rather than whether or not an objectionable or offensive odour has occurred. By analogy, it is clear that when assessing whether or not the emission of an air contaminant is likely to cause adverse health effects, we consider the specific mechanism and types of effect upon exposed individuals. Debates over what is the meaning of "objectionable or offensive" are not necessary to the successful management of odour effects on the community provided the effects can be "measured". This report attempts to shift the odour management debate towards a focus upon the "adverse effects" of objectionable or offensive odours, in particular the specific mechanisms and type of effect (ie chronic and acute effects), the criteria for assessing the significance of these effects, and how these are best managed.

To this end "chronic" and "acute" odour effects are introduced as being the two types of adverse effect that can result from "objectionable or offensive" odour emissions over longer and short term periods respectively.

3 DISCUSSION OF TERMS

In this report the terms "chronic" and "acute" are related to different types of adverse or nuisance effects due to odour. The general rationale for making such a differentiation is that the causes of each type of odour effect have consistent differences, which require different management and assessment approaches. Therefore it is possible for both regulators and site managers to streamline their assessment and management approaches, having ascertained the type of odour effect that is most dominant (in many cases only one type of effect will be occurring). A clarification of odour concentration units is also provided.

3.1 Chronic Odour Effects

Chronic odour effects result from the long-term exposure to repeated impacts of objectionable or offensive odours over an extended period of time. In many situations it is the repeated nature, and accumulated effect of the odour events that is the problem, whereas individual events are not necessarily significant. The environmental significance of the associated effects is a function of the FIDOL factors[3]. Chronic odour exposure often results from process emissions that may be continuous or periodic in nature. The local wind patterns at the site generally control the significance of odour impacts at different locations within the surrounding area.

3.2 Acute Odour Effects

As for noise or dust nuisance, there are also those occasions when a single odour event is so strong or acute that it is unacceptable, or has caused an adverse effect. This is irrespective of the fact that they may occur infrequently, such as twice a year.

The term "acute odour effect" relates to the adverse effect due to the short-term exposure to objectionable or offensive odours. Such circumstances typically arise from abnormal process emissions or infrequent activities that emit a large quantity of odour into the air for a limited period of time; an example being the crashing of an aerobic wastewater treatment pond. These types of odour emissions are often (but not always) related to the management systems at the site. Another example being the measures taken to minimise anaerobic landfill gas leaks when re-opening old areas of fill, to commence a new layer of a developing landfill site.

3.3 Equivalent Terms

Objectionable or offensive odours can cause adverse effects by either *chronic* or *acute* exposure that can result from continuous/semi continuous or occasional/infrequent odour emissions respectively. It should be noted that the distinction between immediate and accumulated odour-effects, is not new for odours or air contaminants in general. For example the assumptions regarding the concentration at which odours become annoying, or reach an "annoyance level" (often 5 ou/m^3), could be restated as *"the concentration when odours can cause acute adverse effects"*. Whereas the assumption that a specific percentile odour concentration (long term

exposure level) is likely to result in excessive "population annoyance" could be restated as *"the percentile odour concentration that results in chronic adverse effects"*.

3.4 Odour Concentration

The term odour concentration gives the impression of an absolute quantity, when in fact the concentration values quoted are always multiples of the concentration of the absolute odour that can be just detected; known as the detection-threshold concentration. Furthermore this ratio for odorous air is always determined by sampling the air and establishing how many parts of "fresh" odourless air need to be added (that is how much dilution with fresh air is required) to make the odour in the original sample only "just detectable". The amount of fresh air required to reach the "just detectable" state is often called the number-of-dilutions-to-threshold (NDTT) or dilutions-to-threshold (D/T). The Europeans have defined the term odour units (OU) [5]. This definition means that odorous air with an odour concentration of say 100 OU/m^3 requires a 100-fold dilution with fresh air for its odour to be "just detectable". Therefore odour concentration units such as (OU/m^3), (N/T), or (NDTT) are all equivalent, that is a dilution factor to reach a threshold of detection. Therefore all of these concentration units represent relative odour concentrations, as they are only relative to the threshold concentration. Furthermore, this threshold concentration is often not known in absolute terms such as in micrograms per cubic metre ($\mu g/m^3$).

The concept of a relative odour concentration may appear to be straightforward. However, the interpretation is made difficult by the fact that the threshold concentration itself has a transient nature and is very much a function of methodology. For example, the average concentration ($\mu g/m^3$) at which individuals can typically "just detect" a chemical compound and therefore its odour is strongly influenced by a number of factors including:

- the device used to dilute to the odorous air;
- the manner in which the diluted air samples are presented to the individual;
- the ordering of progressive dilution factors ie ascending, descending concentrations;
- the environment where the sniffing is conducted;
- the type of response given;
- the total flow rate of air presented to the nose; and
- criteria used to define when the threshold has been reached.

The detection threshold concentration of a chemical compound in the air is thus related to methodology used in the first instance. Therefore relative odour concentration values quoted as either (D/T's) or (NDTT's) or (OU's/m^3) are of limited use unless the method for establishing these is known. This is why standardisation of the methodologies is very important, as it allows for consistent and comparative dilution-to-threshold factors for the same sample odour. This allows for research into exposure versus effect to be replicated and the results used to assist with environmental assessments.

To this end the quoting of D/T or OU/m^3 values in this report are often associated with a lower case subscript. This indicates the method used to determine the number of dilutions-to-threshold. Note that 100 OU/m^3 equates to 100 N/T's or 100 NDTT's, if the same method is

quoted. For example 100 OU_{WSL}/m^3 equates to 100 N/T_{WSL}, where the subscript in this case relates to the Warren Spring Laboratory dilution equipment and laboratory procedures. As another example the old Queensland EPA standard of 2.5 OU, or OU_{QDL}/m^3 does not equate to 2.5 OU_{DUTCH}/m^3, as determined by the Dutch Standard for olfacometry[5].

Despite the above, it has been common practice for odour guideline reviews to compare Dutch, Queensland, Victorian, US and other odour standards in the same units (OU), giving the false impression that the standards indicate similar environmental controls and therefore confirm each others validity. The reality is very different.

4 ODOUR MANAGEMENT ISSUES

A key odour management issue for regulatory authorities and industry is the approaches used for assessing potential odour effects during consent application processes, or when monitoring for compliance with odour conditions. There is a general lack of any well-founded guidelines for determining if significant "acute" or "chronic" adverse odour effects have occurred. The uncertainty that results from the lack of quantitative interpretation of adverse odour effects can ultimately impose too much risk for some industries to develop, or to invest in improved operation. This situation will exist until the following fundamental issues are addressed:

*(a) appropriate population-based **indicators** for the effects of objectionable or offensive odours; and*
*(b) the "**threshold values**" for these **indicators** that indicate at what point objectionable or offensive odours are likely to cause adverse environmental effects".*

Until such a policy is formulated then there can be no common basis for the specification of all odour assessment guidelines, including community-based surveys or concentration guidelines. Section 7.0 recommends both the appropriate indicator and threshold value referred to in (a) and (b) above.

It is often stated that "complaints" are an appropriate nuisance indicator and that any complaint can indicate adverse effects. This approach may work well where there is a substantial residential area surrounding a site, such as in the case of Meadow Mushrooms Ltd[27]. However, odour complaint frequency on its own is not a robust indicator of the true significance of odour-effects that can be applied for a wide range of situations. This does not detract from the use of complaint frequency to justify the implementation of a more rigorous monitoring programme.

Population-annoyance surveys[17] do offer a robust and "transferable" indicator of chronic and acute effects of odour. As for assessing noise-effects, "population-annoyance" is measured directly via a community survey and provides a consistent basis for the refinement and development of odour concentration guidelines. These guidelines can then be utilised with reasonable confidence for assessing the potential effects of a proposed operation. This approach is expanded later in this report, although some other odour management issues are first discussed.

4.1 Assessments by Enforcement Officers

Councils often have a standard policy that odour emissions should not be objectionable in the opinion of a council enforcement officer. Although the phrase *"…to an extent that is likely to cause an adverse effect"* is often absent, the reality is that enforcement officers generally attempt to assess the extent and significance of the odour impacts. These policies can give the impression that when visiting a site, an officer can quickly assess the FIDOL factors and therefore whether or not the odour emissions are causing adverse effects. This is not possible unless the specific odour event is of sufficient intensity and duration to cause an acute adverse effect, which can be assessed from the observations of a single incident.

In the majority of cases, one-off events are not sufficient to take any action, nor are they due to any obvious problem at the site. Ultimately, the officer needs to rely upon feedback from the community to determine whether the frequency as well as intensity of ongoing odour impacts are likely to be causing adverse odour effects. Single observations of an odour event by officers are limited in their usefulness to the cases involving strong "acute" impacts. However the problem is often related to the frequency and duration of recognisable odour impacts (ie. chronic odour effects).

It is considered that false expectations are often created regarding what an enforcement officer can practically achieve and the level of protection that conditions such as *"…no objectionable or offensive effects in the opinion of an enforcement officer …"* can provide to a community. Such conditions do not appear consistent with the RMA, which does not necessarily preclude the occurrence of objectionable or offensive odours per se, but rather that their presence should not cause adverse environmental effects. The difference in meaning may appear subtle, but is nevertheless considered to be an important distinction.

4.2 Community Feed-Back

Community feedback in the form of complaints, or surveyed opinions (including annoyance towards odours) provides a direct indication of the extent of effect from odour emissions. However, the point at which adverse effects can be deemed to have occurred is not clear; with the probable exclusion of odour annoyance survey data. Furthermore, there has been an absence of clear guidance as to the appropriate survey methods to be used for given situations. A number of methods exist, including complaint records, odour diaries and community opinion/odour annoyance surveys.

The procedural aspects and statistical design of survey techniques are well documented and have been previously summarised [9]. This provides a useful summary of techniques and general considerations, but fails to recommend which methods lend themselves to particular situations. More importantly the advice provided tends to relate to the secondary considerations of detailed methodology. In practice there are more fundamental issues to address, such as which "population response" parameters are relevant and which assessment criteria should be used. This is analogous to specifying detailed protocols for the use of speed cameras for controlling vehicle speeds, while omitting the specification of speed limits themselves.

4.3 Olfactometry

4.3.1 Standardisation

The European community has now developed a draft standard for olfactometric procedures, which is based on the original Dutch standard method. The Dutch pioneered the development of olfactometry into the environmental field. In the early 1990's New Zealand reviewed the Dutch procedures and those less detailed yes/no based methods used in other countries and has since followed the European developments. Standards Australia and New Zealand are now working jointly on the development of a common odour measurement standard, which is likely to adopt

the European procedures with some minor modifications. It also appears that certainty-threshold data will be preferred over the use of detection-based data.

4.3.2 Certainty versus Detection Based Thresholds

Some confusion in the interpretation of olfactometry data has resulted from the recent trend towards the use of "certainty " based odour concentration values, as opposed to "detection" based odour concentration values that have been previously quoted. There are also differing reports regarding the appropriate scale factor to apply, when converting between the two types of threshold data.

The use of certainty-based concentrations as well as detection-based concentrations has been promoted in Europe[6]. The initial evidence from two European based forced-choice olfactometers in New Zealand and those operated by TNO in the Netherlands had consistently indicated that the average ratio of detection to certainty-based concentrations was a factor of 2. However a recent reports have indicated that this average ratio to be closer to 3.5. Whether some laboratories are consistently different to others, or if there has been a recent trend towards a higher ratio in general is difficult to establish.

Certainty threshold concentration values result from a simple modification to the detection-based threshold procedure, that requires the panellists to make a subjective judgement regarding their "certainty" of detecting odour in a sniffing port which they have chosen. This subjectivity is absent from the objective detection-threshold procedure, which is based solely on an analysis of correct and incorrect decisions/choices of panel members.

The notion that certainty-threshold concentration data is more repeatable and reproducible is not supported by any published data to date. Furthermore a number of large olfactometry in New Zealand, have indicated that certainty-based thresholds were not more repeatable than the corresponding detection-threshold concentration results.

The development of certainty-based threshold method seems to have arisen more from the need for compromise in methodology, when developing a common European standard[6]. However, in terms of obtaining more repeatable and reproducible data there only appears to be disadvantages in the use of certainty in preference to detection-threshold based odour concentration results due to the introduction of subjective decision making to the process.

The current draft of the joint Australian and New Zealand standard for odour measurement using olfactometry is very similar to the draft European method and defines both certainty and detection based odour concentrations. The assessment of appropriate case studies would help confirm which concentration threshold type is the most suitable for use in a modelling guideline and whether or not the ratio between the two types of concentrations, that a laboratory typically achieves, needs to be accounted for or not.

It is recommend that the use of certainty versus detection-threshold data for odour concentration guidelines is reviewed in the future using case study information. Furthermore, that the current trend to use certainty data does not become inflexible, as it may eventually be confirmed that detection-threshold concentration has clear advantages. Note that both types of threshold are defined for potential use within the draft Australian/New Zealand odour measurement standard.

4.3.3 Inappropriate Use's of Olfactometry Technology

4.3.3.1 Use of Hedonic Ratings of Odour

The use of olfactometer panellist ratings of odour to derive odour guidelines represents a significant misuse of olfactometric technology. The correct use of this technology involves the generation of repeatable and reproducible odour concentration data from a source. This can then be used as a research or assessment tool. For example, to generate emission rate inputs for atmospheric dispersion models, from which predictions of ambient concentration ou/m^3 can be made.

Olfactometric measurement procedures for odour have been developed to reliably estimate the relative magnitude of "odour exposure" or "dose" that can be correlated against the community response variable (eg. % of community at least annoyed). This process of dose-response research has enabled concentration guidelines for modelled olfactometer data to be derived. The environmental significance of odour concentration data can not be established by an olfactometer and panellists alone. Nevertheless this approach has been used in both Australia and New Zealand in recent years to derive concentration guidelines.

The author's own experience has confirmed that hedonic ratings of an odour's annoyance level in the laboratory are likely to grossly overstate the actual perception in the real environment. During an odour sampling and analysis programme for a large municipal landfill site in Auckland, New Zealand (October 1996), control samples of fresh air were collected for comparison with those collected downwind of the working face. The results were obtained using dynamic dilution forced-choice olfactometry in accordance with the 1995 European standard[6].

The fresh air samples were found to have measurable odour concentrations of around 100 ou/m^3, which is consistent with results routinely obtained for background "fresh" air when using Dutch or CEN methods. However of most interest were the annoyance ratings. Some panellist rated the control fresh air as being at least "annoying" and in one case "quite annoying" even when the original samples were further diluted with ten parts of carbon filtered air. Hedonic ratings of odour samples from a olfactometer laboratory can clearly provide a misleading and overstated indication of the annoyance potential of modelled odour concentrations that result from emission data derived from olfactometric measurements.

4.3.3.2 Enforcement Officers with Calibrated Noses

Another potentially misleading use of olfactometry is the practice in New Zealand to apply the n-butanol screening procedures to regulatory staff and subsequent certification of such staff as having a "calibrated nose" if complying with olfactometer panel selection requirements. The procedure is useful for ensuring that enforcement officers are not nose-dead, or highly sensitive. However, individuals who can detect n-butanol within specific concentration limits are not any more capable of assessing the strength, or character of an environmental odour, than individuals whose n-butanol detection thresholds do not fit within some arbitrary range.

The screening procedure for olfactometer panellists was developed to increase the repeatability etc of relative odour concentration data measurements, which do not consider either the "character", or "perceived strength" of the odour samples. Applying the term "calibrated noses"

to an enforcement officer, may well be misinterpreted by lay persons, including lawyers and judges, as being a person with greater credibility in assessing odour.

4.4 Odour Concentration Guidelines

4.4.1 Appropriate Environmental Target

Regional Plans generally have a policy statement requiring the control of objectionable or offensive odours (and therefore nuisance), as opposed to regulating against odours being detectable, or recognisable at the property boundary. However, the rationale often given for selecting concentration criteria for assessing odours is often based upon an environmental target, which equates to "no detection of recognisable odour" or "no odour detection". Achieving this target will often go well beyond what is necessary to avoid adverse effects from objectionable or offensive odours. The appropriateness of using the "no odour" environmental target is considered to be at the heart of the odour concentration guideline debate.

4.4.2 Comparisons with other Jurisdictions

Another practice adding some confusion to the debate is the tendency for discussion documents and regulatory reviews to quote numerous standards and guidelines from other jurisdictions without details of the measurement methods to which they relate. This creates the impression that odour concentration units are more or less comparable, when the reality is very different. For example, the Victorian EPA ambient criterion of 1 OU is only relevant to the Victorian odour measurement procedure, and is generally applied to point sources. Its relationship to modern European odour-measurement standards is very difficult to determine with reasonable certainty. Nevertheless, concentration guidelines from the various states of Australia are often summarised together with those from other countries. In practice, such guidelines should not be quoted as evidence of what "others are doing" to control odour nuisance, unless the significance of these values can be related back to a referenced and traceable odour measurement standard. This would eliminate the use of values used by virtually all state EPA's in Australia and the USA, because of their inability to comply with the requirement to be referenced back to traceable standard.

4.4.3 Concentration Guideline Development

The annoyance-threshold assumption and use of peak-to-mean ratios, as recently used to develop numeric odour concentration guidelines in Australia and New Zealand are likely to result in overly stringent and unrealistic environmental targets. This is discussed in more detail in Section 5, however in brief terms, it is considered that the methods are based on old and invalid assumptions. Furthermore, this approach appears to be out of step and inconsistent with the findings of more recent European research [9].

There appears to be a considerable lag between advances in olfactometric measurement technology and the development of odour concentration guidelines. For example the assumption of an annoyance threshold for intrinsically offensive odours of around 5 ou/m^3 is based upon twenty-year old olfactometric data. The validity of this assumption when the data is

generated using post 1995 European olfactometric measurement procedures appears to have been over-looked. Any analysis of odour concentration guidelines should ideally include the change in measurement protocols.

The assumption of an annoyance threshold of 5 ou/m^3 is a highly questionable "rule of thumb" that has not been confirmed in the field using modern odour measurement standards. Recent studies suggest that much higher concentration thresholds would be more appropriate in many circumstances, when using post 1995 European olfactometry procedures.

The technical material that is provided to support near or sub-threshold odour concentration guidelines is based upon a theoretical analysis rather than community-based research. It is also considered that the level of conservatism inherent in such guidelines may well be unnecessary and could impose severe economic burdens upon processing industries, or otherwise have the potential to stifle industrial development if widely adopted as an evaluation tool.

4.5 Prescribed Buffer Distances

Prescribed buffer distances that are contained within Industry Codes of Practice, are generally based upon industry experience. However, the extent of odour exposure levels as a function of distance from a source are generally specific to the location of the source. Different topographic features surrounding a site combined with its predominant wind pattern can dramatically influence the downwind odour exposure levels for different directions and for the same distance from the site. This can result in a location close to a facility having substantially less odour exposure than a site located further away in a different direction. Therefore, prescribed buffer distances can be unreliable when assessing the adequacy of separation distances between a site and surrounding residential areas. They also suffer from the problem associated with the subjective interpretation of objectionable or offensive odours and the absence of any community-based research to support their development.

Despite the past failures, prescribed buffer distances are still proposed as a planning tool that councils could use[2]. This is unfortunate, as they are an unreliable management tool for protecting against significant adverse effects.

4.6 Industry Codes of Practice

Industry codes of practice are ideal for assisting regulators in their understanding of the "best practical technologies" and mitigation options for a specific industry, as well as providing industry members with guidance on good odour management practices. However, the outstanding problems in odour management relate to odour assessment and monitoring methods. The development of industry codes of practice on their own will not help solve these problems.

5 DEVELOPMENT OF CONCENTRATION GUIDELINES

In this section the assumptions, rationale and supporting evidence used to develop odour concentration guidelines are discussed. This follows a discussion of some fundamental concepts and issues.

5.1 Fundamental Concepts

The fundamental concepts of odour perception and effects have been discussed in various reviews[2,3,11], however for convenience a brief discussion is provided.

Odour is a sensation associated with a variety of compounds which, when present in sufficiently high concentrations in the air, trigger responses in exposed individuals. As for noise, whether or not an unpleasant sensation causes an adverse effect, generally depends on various interacting factors such as typical intensity and character of odour impacts, as well as other social and environmental factors. Finally, the general population displays a statistical variation in physiological sensitivity to odour, to the extent that some people are at least 100 (sometimes 1,000) times more sensitive than others.

The detection of an odour stimulus occurs on very short time scales, less than one second. However, it is unlikely that such short-term exposures cause significant adverse effect unless these are very intense and have long durations.

5.1.1 The FIDOL Factors

The FIDOL factors[2,3,11] relate to the pattern of odour impacts and receiving environment where these occur. These are the same factors routinely listed in Air Plans to assess odour effects. The FIDOL factors primarily describe the character of odour exposure patterns; but are not direct measures of the adverse effects (such as population annoyance etc) of these impacts. Therefore the emphasis placed upon these factors in social surveys is not always an efficient approach. For example having knowledge of these parameters does not necessarily allow for a definitive assessment of adverse effects. This is because there are no equations or even "rules of thumb" that allow us to calculate some criteria from these factors, that indicates the likelihood of adverse effects. This does not detract from the fact that these factors do nevertheless dictate the extent to which objectionable or offensive odours effect individuals and this information can be utilised to assist in making judgements. The factors are summarised and discussed as follows:

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

The *frequency* of odour exposure simply refers to how often odour events occur. It is a function of the variations in odour emissions over time, and of the meteorological conditions in the area

around the source. The frequency of odour exposure is generally greatest in areas that are most often downwind of an odour source, especially under stable conditions with low wind speeds (provided that the odour is not emitted at a significant height above the ground).

The *intensity* of odour in this instance refers to an individual's perception of its strength and does not account for its character, or quality. The perception of odour usually results from multi-component mixtures of chemicals, for which an additive effect of individual odour concentrations rarely applies. The relationship between the perceived strength (or intensity) of an odour and the overall mass concentration of the combined chemical compounds ($\mu g/m^3$), or odour concentration (ou/m3), has the general form of a power law. This is in common with other human senses, such that if the relative concentration of an odour (ou/m^3) is increased tenfold, then it will be perceived to increase in intensity by a much smaller amount.

The *duration* of odour events is controlled mainly by meteorological conditions, although variations in odour emissions may also be important for sources that vary in strength over short time periods.

Offensiveness is a qualitative description of the intrinsic pleasantness/unpleasantness or underlying character of an odour. The exact definition can become confusing and convoluted, as it is often described in terms (such as "hedonic tone") that are a function of concentration, intensity etc. For this parameter to be independent and distinguishable from the others, it should be related to the intrinsic character of the odour that is generally independent of the concentration.

Location is an essential consideration when assessing the likelihood of adverse effects from odours. People working within industrial environments are generally expected to be less sensitive to odours than people within their residential dwellings, or involved with recreation. Considering the location of odour impacts equates to an assessment of the receiving environment sensitivity (RMA, Fourth Schedule).

5.1.2 FIDOL versus Odour Effect

The greater the frequency, intensity, duration and offensiveness of odour impacts, the greater the extent of chronic adverse effect on repeatably exposed individuals, or in other terms "sustained annoyance". Acute adverse effects as described in Section 3 can result from infrequent high intensity exposures to odour. This may contribute to the "sustained annoyance" within the exposed population, or may only have a more temporary effect on the emotions and behaviour of exposed individuals.

In practice the pattern of a particular industry's odour impacts can fall anywhere within the range of frequency, intensity and duration spectrum and therefore be capable of causing both chronic and acute adverse effects. However, the nature of emissions from different industries tends to result in one of these types of adverse effect being more prominent. For example continuous processing plants tend to generate continuous emissions that cause chronic adverse effects. Alternatively, a number of industry types generate little odour emission when operating normally, except in relation to specific incidents, which have the potential to cause acute adverse effects.

5.1.3 Percentile Odour Concentrations Guidelines

It is important to note that percentile odour concentration guidelines that have been developed in conjunction with community surveys typically relate to the potential for chronic adverse effects to occur. However, there appears to have been no similar community-based research that has successfully related short-term odour concentrations to acute adverse effects in the real environment. Consequently, the olfactometry and dispersion modelling approach is less useful for assessing acute odour effects.

Finally, acute concentration guidelines for allowable exposure to air contaminants in general would be much higher in magnitude than required for protection against chronic exposure. Acute and chronic percentile concentration guidelines (ou/m^3) should also follow this pattern.

5.2 Annoyance-Threshold Studies

5.2.1 Early Work

The annoyance-threshold model for assessing industrial odours assumes the existence of a "fixed" threshold concentration (ou/m^3), which if exceeded for a few seconds or more, will cause an adverse effect. This focus ignores the complex interactions of the various FIDOL factors. In practice it would be necessary for the intensity of single odour impact events to be relatively high and persistent for them to be capable of causing an adverse effect, ie an unpleasant experience, or significant loss of amenity. Therefore the annoyance-threshold model should be limited to the control of the more intense impacts, for which "single events" can be justifiably equated to an adverse effect without the need to consider other temporal factors. However, the guidelines that have been developed by this approach have been widely applied to situations where the cause of odour complaints and general population annoyance is related to repeated occurrence of odour impacts from continuous/semi-continuous process emissions (i.e. chronic odour effects).

Therefore the annoyance-threshold model of the population response to industrial odours would only be appropriate when attempting to derive concentration guidelines defining "low frequency high impact" concentration levels for protection against acute adverse effects of odours.

The use of an annoyance-threshold model dates back to the first practice of so called "objective odour regulation" based on an ambient measurement. A description of the method (used in the USA) was reported thirty-eight years ago[12], and was later referred to as "scentometer based regulations"[13]. In this study ambient odours beyond the site boundary were measured directly, rather than being predicted by atmospheric dispersion equations. The number of dilutions to threshold (D/T) results (which equate to the number of odour units per cubic metre) were then compared to a fixed limit of seven times the dilution threshold. (7 D/T, or 7 $OU_{scent.}/m^3$). Huey (1960)[12] stated "*Experience has shown that 7.0 D/T will probably cause complaints...*".

The report of Huey (1960)[12] provides us with anecdotal evidence of an annoyance or complaint threshold equating to 7.0 D/T as measured via a scentometer (ie. 7 $D/T_{scent.}$ or 7 $OU_{scent.}/m^3$), that is an odour concentration guideline for protection against acute adverse effects. Although, as we discuss later, 7 $OU_{scent.}/m^3$ in the 1960's is likely to equate to a much larger concentration (OU/m^3) using olfactometric methods that are accepted today.

The odour concentration standard of 7 $OU_{scent.}/m^3$ considered appropriate by Huey (1960)[12] indicates that modern day concentration guidelines provide for a vastly more stringent end-point than simply avoiding odour complaint, or acute adverse effects. The latter day guidelines are developed from the starting point that the annoyance threshold is 5.0 ou/m^3, as measured by modern forced-choice-dynamic-dilution olfactometry standards[5,6], and these methods are likely to be more than an order of magnitude more sensitive than scentometer readings.

The next influential work appears to have been completed almost twenty years after Huey (1960)[12] by Bedford and Trott (1979) at the Warren Spring Laboratory (WSL)[14]. These workers developed an annoyance-threshold odour concentration of 5 D/T based upon the WSL olfactometer. However, the 5 D/T_{WSL} criterion value was established using different methods to those earlier used by Huey (1960) to define the 7 D/T_{scent}. Firstly this value was based upon an intrinsically more sensitive device than the crude scentometer; the WSL olfactometer[14]. Secondly, the primary method used to establish an annoyance-threshold criterion by Warren Spring Laboratory appears to have been olfactometry laboratory experiments that indicated ratios of 5 to 10 times the detection threshold, that is 5 - 10 D/T_{WSL}, as the annoyance threshold for olfactometer panellists (ie. hedonic ratings).

The work by Warren Spring Laboratory[14] and Huey (1960)[12] appears to have contributed to the commonly held belief that "*odours become annoying at 5 ou/m*^{3}". In practice, threshold measurement methods have become progressively more sensitive, going from the scentometer (1960) to the WSL-yes/no-olfactometer (1979) and now to European standardisation (1990's). Despite this progression in measurement technology and the associated decrease in the "perceived" significance of, for example 5 ou/m^3, the same concentration-value for the "annoyance threshold concentration" is used for developing new guidelines. Note to convert the one-hour average modelling result to a short-term concentration the 5 ou/m^3 is divided by a peak-to-mean concentration ratio. A summary of developments is given in Table 1.

The reported evidence of Huey[12] was clearly based upon his anecdotal experience in the field during the 1950's-1960's. Nevertheless the reduction in odour exposure that 5 ou/m^3 represents using today's olfactometry procedures compared to 7 D/T in the 1960's, is very substantial and difficult to ignore. It would not be appropriate to simply speculate that this reduction is needed to account for the reduction in the general populations' tolerance of odours.

There is little evidence to support that people in the 1960's were any more tolerant of odours, or less likely to complain than is the case today. Instead it is much more likely that 5 ou/m^3 as measured by modern European methods[5,6] represents a dramatic shift away from the environmental target of "no complaint" that the previous scentometer based standard[12] was related to.

5.2.2 Recent Work in Australia and New Zealand

The general procedure used recently in Australia and New Zealand for developing the 1-hour average guidelines in the order of 2 ou/m^3 for area sources and 0.25 ou/m^3 for tall stack sources is summarised as follows:

i. Define an ambient odour concentration (typically defined as 5.0 ou/m^3) that represents a "threshold annoyance level" that should only be exceeded on rare occasions.

ii. Scale this concentration down by a peak-to-mean ratio that accounts for the fact that 5.0 ou/m^3 is predicted via a dispersion model and relates to a one hour average rather than the short-term concentration peaks which will occur in practice.

iii. Define a percentile value that allows for a small level of exceedence (such as 0.1% of the time) of predicted concentrations above the annoyance threshold criteria.

These three steps are discussed in detail as follows:

5.2.2.1 Threshold Assumptions - Past

Based on the report by Huey (1960)[12] it appears that the annoyance-threshold imposed by earlier scentometer-based regulations related to the control of acute adverse effects. However, the threshold developed by Warren Spring Laboratory appeared to be more closely aligned with a "no detection" end-point, because of the vastly more sensitive type of threshold measurement involved, whilst assuming a similar concentration value.

Given its design and operation, it is likely that the scentometer was the least sensitive of all known dynamic dilution to threshold devices including the ASTM syringe method[15]. This latter device was found to give comparable results to Dravnieks and Prokop's dynamic dilution forced-choice olfactometer[16]. These results can be used to conservatively estimate the relationship between $D/T_{scent.}$ and the D/T_{WSL} values. The comparisons made between the sensitivity of the WSL olfactometer and Dravnieks olfactometer reported by Warren Spring Laboratory[14], indicated that 1.0 $D/T_{Dravnieks}$ equated to around 15 D/T_{WSL} on average. Therefore, the nuisance criteria of 7.0 $D/T_{scent.}$ can be expected to equate to > 100 $D/T_{WSL.}$

Therefore, the scentometer-based criteria for controlling acute adverse effects of odour could possibly equate to several hundred ou/m^3 as measured using today's standardised European olfactometry methods[5,6].

The results above are further evidence that the annoyance threshold data reported by the Warren Spring Laboratory[14] of 5 D/T (or 5 ou/m^3) equated to a significantly more stringent end-point than that previously imposed in the USA using the scentometer to measure odours beyond the site boundary. Despite this, the Warren Spring Laboratory cited the experiences reported by Huey (1960)[12], as confirmation of their own assumption validity. Presumably this was due to similarity in the magnitude of their concentration values.

Given the above, the Warren Spring Laboratory annoyance-threshold criteria of 5 D/T is estimated to be equivalent to less than 0.3 D/T, as measured by the scentometer reported by Huey [12].

It is also important to note that Huey's threshold measurement device that was only operated in the real environment to sample and assess the ambient air directly. When Huey[12] commented that "*their experience* indicated that 7 $D/T_{scent.}$ *will probably cause complaint*", we can safely assume that this *experience* related to collective observations of odour complaints versus the ambient $D/T_{scent.}$ as measured in the field. That is observations of odour effects within communities.

The experiments reported by Warren Spring Laboratory[14] relate to descriptions by olfactometer panellists under laboratory conditions. The method assumes that the hedonic rating of "annoying" by panellists who sniff an odour that is diluted with carbon filtered air within a laboratory will correspond to the level of ambient odour concentration that may cause an adverse environmental effect. There is no documented evidence to support this assumption. In fact it would seem very unlikely that this assumption is valid (see comments in section 4.3.3)

5.2.2.2 Threshold Assumptions - Present

Present day annoyance threshold assumptions are generally quoted as being five times the threshold concentration (as per Warren Spring Laboratory[14]). Therefore it is assumed that an adverse effect could occur if the modelled short-term (peak) concentration downwind of a plant could exceed 5 ou/m^3 (using CEN based certainty thresholds[6]). Taking various factors into account, the environmental end-point implied by this criterion would be at least as stringent as the Warren Spring 5 ou/m^3 criterion and probably more so. This can be anticipated from the use of n-butanol panellist screening and sample presentation procedures now required by the new European olfactometry standards[5,6], that have developed since the early 1980's. The effect of these measures is difficult to predict, except that European based odour olfactometers could well be 2 to 5 or more times sensitive than the now old Warren Spring yes/no olfactometer. Note it would be unlikely that Warren Spring olfactometer design and operating procedures would meet today's European standards.

In practice for most industrial odours, both detection and certainty-based odour concentrations of 1 ou/m^3 are likely to be only a fraction of the concentration required for them to be recognised in the real environment. These unity values would be an even smaller fraction of the odour concentration required to cause an unpleasant experience in the real environment.

Therefore the assumption of an annoyance-threshold of 5 ou/m^3 (based on European Standards) is more likely to equate to a "no detectable odour beyond the boundary" environmental target. In many cases this may extend well beyond the requirement to protect the community from acute or chronic odour effects and even beyond the point of detection in the real environment.

5.2.2.3 Use of Peak-to-Mean Ratios

Because the annoyance-threshold model is based upon the premise that the potential of odour to cause an adverse effect can be related to time intervals equivalent to the response speed of the human nose, the use of peak-to-mean ratios was developed.

Peak-to-mean ratios relate short-term ambient concentrations that may actually occur to the 1-hour average concentration as predicted using an atmospheric dispersion model. Therefore the modelled 1-hour average concentration guideline is derived by dividing the assumed "annoyance threshold concentration" by an appropriate peak-to-mean ratio. Peak-to-mean ratios have been studied in detail[17], and are well defined. However despite this sound physical basis, their use in developing odour concentration guidelines does not overcome the more fundamental problems including:

i. the assumed annoyance-threshold model being unrealistic for assessing chronic effects; and

ii. the assumed annoyance threshold concentration being determined in an artificial manner that is likely to grossly overstate people's responses within the real environment.

5.2.2.4 Percentile Exceedence Criteria

Percentile exceedence criteria such as 0.1% of the time (99.9 percentile), or 0.5% of the time (99.5 percentile), allow for predicted odour concentrations to exceed the derived 1-hour average criteria for a small percentage of the time. The 99.9 percentile value was preferred by the Auckland Regional Council (ARC) in developing an odour concentration design standard for the upgrading of the Mangere Sewage Treatment Plant[7]. This time-percentile value was also recommended by Environment Waikato[1]. The rationale given by the ARC for choosing this percentile value is that it relates to the probability that the peak-to-mean ratios assumed would in fact be exceeded.

From a fundamental standpoint, the existence of a percentile value should only be related to FIDOL factor type considerations and not an arbitrary decision regarding risk of exceedence. In other words, it is only appropriate to assign percentile values according to the frequency and duration that communities will find acceptable for a given odour concentration. This also requires that the consideration of percentile values should not be conducted in isolation of specific odour concentration values; the two parameters are inter-related.

A justification often given for the use of a 99.9 percentile exceedence criterion[1] is that the probability of 10^{-3} is based upon a large amount of theoretical statistics, backed by laboratory field studies. Although the science involved in developing the concentration peak-to-mean ratio factors may have rigorous statistical basis, it has little relevance to the assessment of adverse effects of odours and is an example of "misplaced science".

5.3 Community-Annoyance Studies

Community-annoyance based odour guidelines have an identical form to those developed using an annoyance-threshold based approach. However, the approaches used to develop the concentration guidelines are very different. Furthermore the meaning of annoyance is different. In this instance "annoyance" relates to response from sampled members of the population during a survey (ie. population annoyance). An important aspect of "population annoyance" is that it can be observed to increase significantly above a control population response level while still not being sufficient to result in odour complaints. Therefore odour guidelines based upon small allowable increases in population annoyance are likely to result in no odour complaints from reasonable people. Population annoyance levels need to be reasonably high before odour complaints tend to occur.

Odour concentration guidelines can be generated by direct comparison of modelled odour concentrations versus population annoyance survey responses, which is a similar approach to that used for the assessment of a community's annoyance due to noise. The majority of published research using these methods took place in the Netherlands [10, 18, 19]. Germany has also adopted population or community annoyance as the focus of odour management.

The German VDI standard 3883 (Part 1)[30] details the methodology for community assessment of odour annoyance, which is very similar in approach and definition of "population annoyance" to that used in the Netherlands[10]. However the VDI questionnaire also assesses the specific behavioral and emotional responses to the ambient odour loads.

The VDI standard 3883 (Part 2)[31] describes the use of community-based odour panels to routinely record their annoyance at set times of the day (repeat questioning). The annoyance measured equates to a hedonic rating of the odour in the living environment. Therefore it relays information about the immediate effect of an odour impact at specific times (ie acute adverse effects). Whereas the annoyance measured by a single survey[10,30] relates to the accumulated effects of repeated odour impacts over time (ie chronic adverse effects).

Therefore the surveying approach that is detailed in the VDI standard 3883 (Part 2)[31] would seem to apply to investigations of the relationship between odour concentration (ou/m^3) and the immediate reaction of individuals (as opposed to their general level of annoyance). The need to develop such relationships could be reviewed following the successful implementation and use of "population annoyance" survey methods to assist in managing odour effects.

5.3.1 Dose-Response Research

Dose-response research has confirmed that the degree of annoyance or stress experienced by a community as a result of odours can be correlated to the percentile odour concentration that occurs. For example the $C_{99.5}$ concentration, which is the odour concentration (ou/m^3) that is only exceeded for 0.5% of the time or less. A significant aspect of the research of odour concentration and annoyance relationships is that one-hour average odour concentrations are only involved. Therefore it has not been necessary to consider smaller averaging periods to obtain useful correlationships. The significance of actual short-term fluctuations appears to be either small, or else they are accounted for within the correlation. This correlation is portrayed as an "odour annoyance" dose–response curve, an example of which is shown in Figure 1.

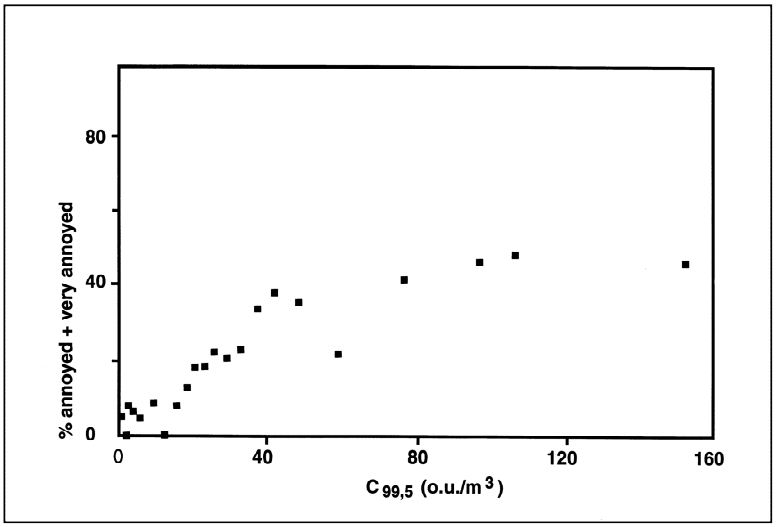

Figure 1: Odour Dose – Response curve (Miedema, 1988)

The Y-axis in Figure 1 is the percentage of the population exposed to the odours from nearby industrial source(s) who reported to being "at least annoyed". This feedback is obtained by carrying out a social survey using standard design and analysis protocols[10]. The corresponding level of time-accumulated exposure to odours (ie. percentile odour concentration) is established by odour measurement at the industrial site and the use of a standard dispersion model with a full year of local meteorological data[10,18,19]. It should be noted that there is nothing particularly special about the 99.5 percentile. When other percentile concentrations are used, the response-curves adjust in a manner that reflects the exposure time that the specific percentile defines. Therefore the percentile value (%) and concentration value (ou/m^3) are intrinsically linked and should not be considered in isolation when developing concentration guidelines.

The research conducted to date has consistently found a good correlation between population annoyance level (%) and percentile odour concentration values (ou/m^3). This relationship demonstrates a non-zero level of population annoyance (typically in the range of 5% to 15% annoyance). The 99.5 percentile concentration where this occurs equates to the level of odour exposure that causes no measurable effect upon the community annoyance level. This is considered to be a useful means for objectively defining when "objectionable or offensive" odour effects have occurred.

It should be noted that because odour dose-response relationships are empirically based, all factors such as peak-to-mean ratios, hedonic tone of the odour involved, day to day exposure profiles and all complex social/cultural factors are accounted for. This is because the responses are obtained from the people within the real living environment and not from individuals who are placed under the artificial environment of an olfactometer laboratory. The laboratory environment is controlled to produce repeatable and reproducible odour threshold measurement values. This environment is not intended to replicate that of the real world.

5.3.2 General Research Methodology

The general process for completing an annoyance dose-response investigation is summarised as follows:

Site Selection: Appropriate study sites have to be selected with care to ensure that reliable information can be obtained. The features of a good study site include:

- Existence of some odour effects in the community;
- Local topography not too complex to model;
- Quantifiable odour sources at the site; and
- Suitable population density and demographic variation.

Odour Emission Measurements: Odour emission rates are quantified using dynamic dilution olfactometry [5,6]. A rigorous sampling programme is required to ensure that any temporal variations in the odour emission rates are well defined.

Sampling procedures need to follow an agreed method, particularly for area sources, where wind tunnel designs can have a large effect upon the outcome. In New Zealand there has been a history of using simple wind tunnels that operate using nitrogen gas, whereas in Australia much

larger fan driven filtered-air systems have been used. The nitrogen gas operated tunnels are likely to give more consistent data and are far more practical to operate in varied industrial climates and would be the preferred choice for New Zealand. It simply remains for a standard tunnel design and operating conditions to be agreed upon.

With regards to tunnel wind speed there are two general schools of thought. One states that the tunnel conditions should represent the concurrent wind conditions. Whereas the other approach is to operate the tunnel such that the turbulence as represented by the Reynolds number is consistent and sufficiently high so that the odour emission rate from the surface is not boundary layer limiting. Given the desire to develop reproducible emission results then the latter approach would be recommended.

Atmospheric Dispersion Modelling/Meteorological Data: A simple gaussian plume dispersion model, such as Ausplume[20] is used to predict percentile odour concentration contours within the community that surrounds the site and including sub-sections of the population that range from being close to far away from the industrial site. On-site meteorological data for a minimum period of one year is also required to allow for accurate prediction of percentile odour concentration values. Two-dimensional contours of various percentiles (98, 99.5 and 99.9) are usually generated for 1-hour average odour concentrations.

Community Annoyance Surveys: The odour annoyance survey is conducted by a standard telephone interview protocol, which is replicated for all investigations[10,18,19]. The protocol is specifically designed to minimise the effects of biased responses and obtain a response that is directly comparable to other studies including those involving control populations.

It is necessary to define the "community response parameter" measured by these surveys. The response parameter is described as "% at least annoyed" and represents the percentage of individuals within various sub-sections of the survey site that reported to the categories "annoyed", "very annoyed" or "extremely annoyed" when asked to rate their level of annoyance from industrial odour impacts.

The term "population annoyance" is in fact a general reference to the numerical value of "% at least annoyed". This parameter is a measure of the accumulated impacts of ambient odour on the population. Population annoyance is a function of the pattern of past and present experiences of industrial odours that have occurred within a specific sub-area of the affected community over a given time.

The meaning of "annoyance" as used in developing annoyance-threshold based odour guidelines (section 5.2 above) is therefore fundamentally different to its meaning when used in conjunction with community-annoyance based guidelines. The former relates to the immediate response of an individual to an unpleasant odour, whereas the latter is a sustained condition (state of mind or level of stress) that some individuals are experiencing because of the situation.

It may seem reasonable for population annoyance within a community to fall to zero when industrial odours are not present, but this does not happen in practice. When annoyance surveys are conducted in relatively unexposed areas 5%-15% of the community typically report to being "at least annoyed" by industrial odours. Therefore the significance of population annoyance data needs to be compared to the baseline level of annoyance. The existence of a non-zero

response is not necessarily a specific feature of population odour annoyance surveys alone. Nevertheless its existence needs to be accounted for when assessing the environmental significance of population annoyance survey data.

The failure to correctly interpret population annoyance survey data often results in erroneous conclusions being drawn about the level of environmental protection that community annoyance based guidelines impose. For example percentile odour guidelines that allow for 10% population annoyance will generally equate to no significant environmental effects and would allow for odour exposure levels that could be expected to be well below the threshold of complaint. However, such guidelines are often viewed as only protecting 90% of the population and therefore incorrectly infer that 10% will be adversely effected and may well complain.

Odour versus Community Annoyance Curves: Population annoyance results are correlated to percentile odour concentrations using multi-regression techniques. It is considered that the extrapolation of these curves into the low odour exposure range results in annoyance being over-predicted due to the "range-effect" phenomenon[10], which occurs when below zero responses are not possible.

5.3.3 Derivation of Concentration Guidelines - Netherlands

The key consideration when deriving odour concentration guidelines from community-annoyance data is the desired environmental target defined by the level of "population annoyance". The Dutch have a national goal that aims to reduce population annoyance to only 12 percent, which has become the bench mark for setting percentile concentration guidelines. This has resulted in a range of 98.0 percentile guidelines from 1 to 7 ou/m^3 (certainty) for different types of odour source. Given that equivalent 99.9 percentile values are typically 3 – 6 times higher than 98 percentile values, this equates to 99.9 percentile guidelines in the range of 3 – 40 ou/m^3 (certainty-based) and 6-80 ou/m^3 (detection-based).

Because these guidelines are a direct consequence of Dutch community responses, it may not be appropriate to assume this range for New Zealand. This aside there is obviously a significant range in the odour guidelines that are applied to industries.

Finally, it is significant that after the completion of numerous studies of odour-dose versus population annoyance, that the Dutch guidelines do not differentiate between point and area sources. This provides some evidence that the peak-to-mean ratios for a specific source, as used in the development of annoyance-threshold based guidelines, are an unnecessary consideration.

5.3.4 New Zealand/Australian Studies

Although no formal odour-dose versus community-annoyance investigations have been completed within New Zealand or Australia, there has been some useful work that is discussed below.

Tasman Pulp & Paper Co Ltd, Kawerau, New Zealand: During 1996 Tasman Pulp and Paper Company Ltd utilised odour-dose versus population-annoyance relationships to assess odour control options for its kraft pulpmill site at Kawerau (Pattle Delamore, 1996). The odour control

options and method of assessment have been well reported[21,22,23,24,25]. The mill investigated a number of odour reduction options ranging in costs from 20 million to several hundred million dollars.

To assess the options, a series of dose-response curves developed from Dutch studies were utilised[19]. However, before these were used an independent odour annoyance survey was conducted to directly measure the percentages of people who were annoyed to various degrees. The survey was conducted following the protocols and procedures detailed in [10,18,19]and included the Bay of Plenty Township of Edgecumbe (151 people surveyed). This township has approximately 2000 residents, is about 14 kms way from the mill and was predicted[23] to have a 99.5 percentile odour concentration of 33 ou/m^3 (detection-based). For this concentration the Dutch dose-response curves predicted virtually the same annoyance levels as those obtained via an independent odour annoyance survey. The results indicated that the dose-response curves, although developed for other industries and using Dutch community response, would be a useful tool for assessing the relative benefits of various odour control options.

The outstanding issue for the mill and local council, was the absolute level of odour reduction that Tasman needed to achieve. This required the project team to consider what might be an appropriate percentile concentration standard. The Dutch dose-response curves used for this project indicated that a percentile 1-hour odour concentration of 15-20 ou/m^3 (detection) for 0.5% of a year, is likely to equate to a no-effect level regarding population annoyance[25]. Based upon the requirement for minimal public complaint, then the appropriate 99.5 percentile value would be close to the previous exposure level of about 30 ou/m^3 (1-hour average). This is based on the relatively small fraction of percent of the total population that routinely complain about odours from the mill.

The Tasman Pulp & Paper mill project did not set out to develop an odour guideline. However, the study indicated that odour guidelines in the order of 0.25 to 0.8 ou/m^3 do appear to be overly stringent. Such guidelines result for the assumption of 5 ou/m^3 divided by a peak-to-mean concentration ratio.

5.4 Community-Complaint Studies

Community-complaint based studies are conducted as described above for community-annoyance studies; both are empirical relationships of a community response compared to modelled concentration data. The difference between the two is the response parameter used, and therefore the collection method and interpretation of data is different. A number of community-complaint case studies are discussed below.

5.4.1 Case Studies

Meadow Mushrooms Ltd, Prebbleton, New Zealand: The old Meadow Mushrooms site at Prebbleton was one of New Zealand's longest running odour nuisance disputes. The New Zealand Parliamentary Commissioner for the Environment discussed the twenty-year case history in depth in a milestone review of odour nuisance control laws in New Zealand.

The site was the first to have odour emissions quantified using an olfactometer and procedures that followed the Dutch standard for olfactometric measurements[5]. The original odour emission data related to an n-butanol calibrated panel using the same calibrated olfactometer that was later used for the Tasman Pulp and Paper investigation[27]. The emission data were modelled using AUSPLUME[20] and compared to complaint records from the previous 15-year period.

People who lived beyond the complaint boundary were interviewed in 1996 to assess the extent (if any) to which they were annoyed by the operation, which had closed during the previous year. This was completed in an attempt to assess the extent of annoyance beyond the complaint zone. The results of this assessment indicated that the 1-hour average 99.5 percentile concentration below which odour complaints should not occur was 30 ou/m^3 (detection)[27]. The odour contours summarised in that study also demonstrated that the 1-hour average 99.5 percentile concentration of 4 ou/m^3 (detection) extended into distant areas of the Christchurch City and the Selwyn District where even the "detection" of mushroom compost odours was very unlikely to have occurred.

The Meadow Mushrooms case study provided the first relationship between community response and modelled odour concentration data to be generated within New Zealand. The results indicated that for an area source, the modelling guideline of 2 ou/m^3 (1-hour average, certainty) is reasonable, but for would have overstated the extent of adverse effects due to the existing activity at Prebbleton, Christchurch.

Penrith Sewage Treatment Station, Sydney, Australia: The Kaye study of a sewage treatment facility in Sydney was conducted only recently[28]. Like the Meadow Mushrooms case study it established the link between observed levels of complaint and percentile odour concentrations. The odour concentrations of the plant emissions were measured in accordance with the Dutch Standard[5] and ambient concentrations were modelled using AUSPLUME[20]. The measurement of areal odour emissions was achieved using a wind tunnel, and the resulting data were adjusted for actual wind speed. The community was alerted to the study by means of regular advertising, and so the community response may have been enhanced. Nevertheless the study found that for sewage plant emissions, 99.5 percentile concentrations below 46 ou/m^3 (detection) are unlikely to lead to complaint. This is reasonably consistent with complaint criteria implied from the mushroom-compost production site study above. However, the act of alerting residents to the investigation may well have biased the study. Again the survey results would support a 2 ou/m^3 (1-hour average, certainty) odour modelling guideline for evaluating new activities.

NZ Starch Products Ltd, Auckland: NZ Starch is situated in the suburb of Onehunga, Auckland and had odour emission rates quantified in 1997 from its main air emission sources using European methods[5,6]. There were three odour complaints since 1994, but it was not clear if these complaints were actually attributable to the plant. Therefore at face value, the site did not have a significant odour problem. Despite this the preliminary odour modelling results indicated that the odour guideline of 5 ou/m^3, 1-hour average, certainty-based and divided by the appropriate peak-to-mean ratio value, would extend beyond 2.0 kilometers and more. The differences between experience and the predictions using the above odour modelling guideline was alarming and provided evidence of the potential problem that should such guidelines pose for stack discharges to air.

5.4.2 Summary

In summary the difference between concentration guidelines that can be implied from empirical community-based studies and those derived largely by desktop analysis, is more than one order of magnitude for stack sources. For area sources there less of an issue because of the smaller peak-to-mean ratios involved.

6 COMMUNITY RESPONSE TO ODOURS

Community response on odour impacts creates the primary driving pressure for regulatory action and policy development. Furthermore the assessment of odour impacts and the development of robust odour guidelines relies upon effective community surveying techniques. The methodologies available have been documented[9]. However, the appropriateness of different survey types and associated criteria for interpretation of results, needs further explanation.

6.1 Complaint Records

6.1.1 General

In some circumstances, odour complaint records are good indicators of industrial odour emissions causing chronic or acute adverse effects. These circumstances include situations where:

- a relatively dense urban or semi-urban population is affected; and
- complaint records can be validated against wind direction at the time of complaint.

A good example of a situation with the above features involved the now closed mushroom-composting site at Prebbleton, Christchurch. In this instance the fact that the odour emissions were causing adverse effects was very obvious. However, in many situations the significance of effects is not so clear. For example the population density may be low, or complaint records are not validated against wind conditions and site operations at the time. In such cases, complaint-records are often an unreliable indicator of the true significance of adverse effects being caused[29] and more detailed investigations are often necessary. Decisions regarding regulatory actions are often difficult to reach in such circumstances.

6.1.2 Trigger for Detailed Review

Irrespective of their limitations, the monitoring of adverse odour effects and the decision on whether to take action against an industry for noncompliance is generally based upon public complaint records. Usually the action taken involves site visits, council staff assessments and review of processing records. Some councils will arbitrarily specify a critical complaint frequency that defines when an odour nuisance incident has occurred. However it would be most appropriate for odour complaint frequency to be only used as justification for a more rigorous assessment of the true extent of adverse effects. These more rigorous procedures could include annoyance surveys, odour diaries and in some instances olfactometry dispersion modelling.

6.1.3 Gathering Complaint Records

Complaint records should define when and where the odour incident occurred. The complaint can then be validated against independently recorded wind direction records. This information indicates whether or not an alleged source was upwind at the time of the complaint.

It is also important to establish if the record is a true complaint, or simply an observation of detected odour. Apart from a description of the *character or type of odour* (eg. rendering, stockyards, sewage etc), a general description of the *relative strength* should be made.

A recommended procedure for councils to use when responding to odour complaints by a council enforcement officer are listed as follows:

- Record time and location of complaint and complainants description of the alleged odour event;
- Contact appropriate staff at the alleged source of odour and advise that an odour complaint has been received and that the council will be investigating the incident;
- Record time that source was contacted, who was spoken to and details of conversation;
- Complete a site visit report that details -
  a)The location of complainant
  b)The character and strength of odour over at least a 30 minute period
  c)The wind direction and general weather conditions
  d)An assessment of air upwind of source and complainants location
  e)A confirmation of likely source or sources of odour
  f)The staff contacted at identified source and note the site's operating status
- Provide a copy of the enforcement officers investigation report to the site management and records any feedback provided.

6.1.4 Assessment Criteria

Any discussion regarding criteria for assessing the significance of odour impacts from complaint records should be limited. Ideally such criteria should not be defined, as there is no sound basis for doing this. This aside it is appropriate to use validated complaint records that demonstrate a consistent pattern of odour complaints being generated from areas of a community downwind of a site, as evidence of the frequency of odour impacts occurring within a community due to a specific source.

6.2 Odour Annoyance Surveys – Appendix A

Odour annoyance surveys (or population annoyance surveys) have been discussed in this report, including the situations where they are best applied (Section 5.3). However, there remains the issue of criteria for which the survey results should be compared against.

From experience to date and European studies it would seem that 15%-20% (at least annoyed) is a reasonable limit to control odour impacts to a level that is not "objectionable or offensive" to the average reasonable person. This is not necessarily an allowable level of annoyance that a number of industries could impose on a specific community, as the cumulative effects could become unacceptable. Therefore the annoyance limit is comparable to many other MfE ambient guidelines, that generally relate to cumulative impacts.

It should be noted that the completion of further odour surveys of New Zealand communities would help refine the range of this value for New Zealand.

Defining an acceptable level of odour effect in terms of allowable percentages of people within a population who claim to be "annoyed", "very annoyed" or worse when surveyed, provides a basis for developing consistent concentration guidelines and criteria for assessing and monitoring odour impacts. The case study for AFFCO Wanganui is summarised below to help explain the concepts discussed above.

AFFCO NZ Ltd, Wanganui, New Zealand: During 1997 AFFCO organised an independent surveying organisation (Colmar Brunton, Auckland) to conduct a community annoyance survey within three sub-areas of Wanganui. The survey was conducted following the protocols and procedures used for Tasman Pulp & Paper Co Ltd and detailed in the literature[10,18,19]. The aim of the survey was to establish the current level of odour impact and to assess the methodology and response parameter (% at least annoyed) for their appropriateness in future surveys that aimed to monitor the effects of AFFCO's rendering plant odour at Imlay. The survey involved 233 randomly selected residents split between three separate survey areas (> 70 interviews per area). The areas were selected for high exposure, medium exposure and a control site as follows:

- Close to the AFFCO site and considered to be representative of the most affected areas
- About 1.5 kms away from AFFCO and considered to be representative of moderately affected areas; and
- About 3.0 kms away from AFFCO and considered to be a zone that is not affected (i.e. A control area).

The population annoyance level showed a clear trend from high exposure close to the plant (80% at least annoyed) to a medium exposure 1.5 kms from the plant (40% at least annoyed) and a control site 3.0 kms away (14% at least annoyed).

The above results provided the first confirmation of what the typical base-line response (control site) would be for a New Zealand urban community (i.e. 14% at least annoyed). This was obtained for an area near the central business district of Wanganui City where industrial odour impacts and associated complaints were considered to be absent by District Council environmental health officers.

The Wanganui study was a test of the ability of the (% at least annoyed) response parameter to reliably indicate the extent of odour annoyance, or significance of odour effects using particular protocols and procedures[10,18,19]. The results were consistent with the general finding in overseas studies using the same protocols, that 5% to 15% of the population in areas not exposed to industrial odours will report to being "at least annoyed" when surveyed. Since this project there have been further odour annoyance surveys undertaken in New Zealand (Tasman Pulp & Paper, Bay of Plenty, PPSC Ltd, Christchurch, Cerebos-Greggs Ltd, Dunedin). The results of all these projects would support the upper limit of 20% "at least annoyed" as appropriate guideline.

6.3 Odour Diaries – Appendix B

6.3.1 General

Odour diaries are a community monitoring option for quantifying the zone of influence from a specific odour source and associated characteristics of the odour exposure pattern. This is different from an odour annoyance survey, which directly measures the "adverse effect" of the odour exposure patterns by measuring population annoyance level.

Odour diaries provide a method of obtaining information from the community regarding odour impacts. The information is usually sought from a sub-group of the community, rather than being passively received by a regulatory agency or industry.

The aim of a diary programme is the collation of information on the frequency of strong, moderate or weak odour exposures, at various locations, over a defined period of time. The resulting data can be used to calculate the percentage of time (hrs/year) that people are exposed to industrial odours from a specific source. The longer the monitoring period, the more accurate the calculated results.

6.3.2 Analysis of Odour Diary Results

The data obtained from an odour diary programme needs to be validated by checking the wind-direction and industrial site status during the time of each recorded odour event. The total number of odour events versus duration can then be summarised for those events confirmed to be valid versus those due to other sources. The validated data would also be used to estimate the percentage of time for each month (hrs/month) that each panellist was exposed to industrial odour.

6.3.3 Odour Diaries Versus Annoyance Surveys

It is important to decide whether an odour diary or annoyance survey is more appropriate for a given situation. The former characterises the pattern of the odour impacts (ie the FIDO factors), while the latter is a more direct measure of their effect on the community. Therefore odour surveys, apart from being simple and efficient to conduct, provide the most pertinent information (ie. the extent of population annoyance). However, when the population density is insufficient to provide statistically valid survey results, then an odour diary is generally the next best option. For example the parameter "% at least annoyed" (section 5.3) is of little use when only a small number of people are effected. In this instance gathering information regarding FIDO factors may be the only practical assessment approach.

Odour diary programmes are also a better option, when it is important to monitor the impacts from a specific source within a defined time frame. For example, monitoring the performance of odour reduction measures as they relate to a specific source of odour. An annoyance survey will not indicate the true reduction in "effect" for a considerable time after a real reduction in odour impact has been achieved (up to one year for instance). In some cases there will be other sources of odour that will suddenly appear as a new source, once the previously prominent source has been effectively controlled. The consequence being that reduction in "% at least

annoyed" levels (as measured by an odour survey) after a year or so, may not fairly indicate the reduction in odour impact achieved for a specific source. This phenomenon is not uncommon. For example, the closing down of a rendering plant at Wairoa, New Zealand led to complaints from the previously "masked" wastewater treatment ponds. Although odour diaries are more time consuming and cumbersome to manage they do enable an assessment to be more specific to an odour source and time frame.

7 MONITORING AND ASSESSMENT OF ODOUR EFFECTS

7.1 General

The problems and uncertainty arising from the reliance upon complaint records and subjective assessments by enforcement officers are well recognised. The development and proposed use of bottom-line population annoyance criteria is considered to be a practical approach to achieving a more consistent and predictable level of enforcement action. In addition there needs to be general guidance provided on the choice of appropriate odour assessment tools.

Both chronic and acute adverse odour effects can result in increased levels of population annoyance, both of which can be measured directly by community survey. However other assessment tools can not be assumed to apply to both types of adverse effect. For example the prediction of 98.0 or 99.5-percentile odour concentrations is effective for assessing semi-continuous or process related odour emission sources (ie. chronic effects only).

The significance of relatively infrequent acute odour exposure is not effectively assessed by such percentile odour concentrations. Instead the concentration that occurs during the actual event is more relevant. In other words it is necessary to focus on a much higher percentile value[19]. As another example, the use of an enforcement officers opinion from limited observations is not effective when the problem is caused by a high frequency occurrence of low intensity odour impacts that individually, do not cause significant adverse effects.

Because strong and infrequent odour events are often a result of mishaps, non-compliance with method-based conditions or otherwise abnormal discharges to air (analogous to a chemical spill), then it may be appropriate to require immediate measures to ensure that management procedures are improved.

7.2 Environmental Guidelines for Odour

7.2.1 Acute and Chronic Odour Effects

The Dutch have a national policy of obtaining a 12% level of annoyance, the basis of which is not clear. Although, such a percentage of "at least annoyed" people is within the range of odour impacts that causes a statistically insignificant increase in annoyance from that of an unexposed population, that is the base-line response level. New Zealand has never had a defined bottom line target for "allowable" population annoyance level. The results from Wanganui seemed to confirm a base-line community response level of 15% at least annoyed (section 5.3). Therefore an initial range of 15% to 20% appears to be a reasonable level of allowable annoyance, which is likely to limit odour exposures to a level below that which leads to odour complaint, and which avoids adverse effects on the community (ie. objectionable or offensive effects).

An important aspect of defining population annoyance guidelines (ie. "% at least annoyed") is that this parameter naturally accounts for varying degrees of sensitivity of communities to their specific source of industrial odour. For example the parameter will reflect all of the complex interactions of the FIDOL factors. Where the source of industrial odour is also the major

employer within a community, then it can be expected that a higher frequency and intensity of odour impacts would be acceptable than might otherwise be tolerated for an industry with minimal social and economic benefit to that community.

Recommendation 1: Assessment Guideline for Chronic and Acute Odour Effects

That a standard is defined for the protection of the population from acute and chronic adverse effects of odours.

The parameter to be specified shall be "percent of the population at least annoyed" or "%-at least annoyed".

The maximum allowable level shall be no greater than 20% at least annoyed for residential, commercial and retail zones."

The proposed environmental guideline provides criteria for comparison of community survey information or guidance for the development of any future numeric odour guidelines using community response based studies. This provides an objective definition of when objectionable or offensive odour effects are likely to occur. Finally, all modelling concentration guidelines and odour management policies can be linked to this underlying effects based guideline value.

7.2.2 Acute Odour Effects

The effects of infrequent acute odour impacts can be measured by an odour annoyance survey and therefore protection can be achieved with the above guideline (Recommendation 1). However, the short term and intense nature of this type of impact, may require additional protection to that provided by the population annoyance criterion. For this reason it is recommended that some additional criteria are developed and specified for controlling the acute adverse effects of intense short-term odour events (in addition to the annoyance criteria of Recommendation No. 1 above).

The immediate effect of acute odours manifests as specific individual behavioral and physiological responses/reactions such as "made to feel sick", "shutting windows" and "loss of sleep". Therefore the guidelines could also specify these specific behavioral effects for providing a consistent benchmark for assessing community responses, or possibly developing short-term concentration guidelines.

Where the appropriate form of odour concentration guideline for achieving population annoyance goals is either the 99.5 or 98.0 percentile concentration, the guideline for acute effects would be a fixed odour concentration that is not to be exceeded on any one occasion, and for a specified time frame. This would be similar to the old scentometer-based regulations used in the USA and the effects they were attempting to control.

Acute odour concentration guidelines could not be reliably developed using olfactometry assessments for reasons discussed in section 4.3. Instead it would be necessary to record community odour panel responses concurrently with ambient concentrations that occur during specific odour impact events. In theory this is possible as acute effects are expected to occur at

relatively high odour concentrations. Nevertheless the process would be difficult to implement. Furthermore, the enforcement of such ambient odour concentration guidelines would require sampling of air beyond the boundary, and the transport of samples to an olfactometry laboratory. This would be relatively expensive and cumbersome. The alternative approach is to simply rely upon the enforcement officer's opinion as well as community feedback.

The development of a concentration guideline for acute odour effects would be very difficult in comparison to percentile concentration guidelines for controlling the level of population annoyance and is therefore not recommended.

Recommendation 2: Acute Odour Effects Guideline

It is recommended that further criteria be defined for the protection of the community from acute adverse effects of odours in addition to that proposed in Recommendation No. 1 above.

The criteria include "behavioral and physiological" responses of the affected population to the odour impacts.

That an agreed list of responses be developed such as nausea, shutting windows, and woken up from sleep.

Note: This narrative environmental guideline would provide criteria for comparison of the reported effects from the community via complaint records or odour diary programmes. These would provide some additional protection against infrequent but severe odour events that would be primarily controlled by the population annoyance guideline above.

7.3 Monitoring Odour Effects & Appropriate Response

Having recommended guidelines that define when objectionable or offensive odours are likely to cause adverse effects (section 7.2), it is useful to recommend the appropriate tools for ongoing monitoring and assessment of odour impacts.

Once the nature of the source has been established, that is, whether or not it is caused by continuous/semi-continuous emissions, or infrequent high/uncontrolled odour emissions, and sufficient complaints have been received to justify a more detailed assessment, the following needs to be considered:

- *What are the appropriate monitoring tools in this instance;*
- *How should the information be assessed; and*
- *What are the appropriate responses to expect from the council and company should the assessment programme confirm that the odour effects are objectionable and offensive.*

Table 2 provides guidance on the above decisions with respect to chronic odour effects and the occurrence of acute odour effects. A discussion of the rationale of the recommendations in Table 2 is given below.

7.3.1 Chronic Odour Effects (Section 3.1)

Because the chronic effects are due to normal continuous/semi-continuous emissions, then any attempts by enforcement officers to identify a specific odour event and requirements of company staff to take action to rectify the problem is not an appropriate response. Such an approach is only effective when abnormal odour emissions have occurred and control measures could be practically instigated.

Complaints: Complaint records and site observations by officers are rarely sufficient to imply significant chronic odour effects. Instead a significant number of complaint can be used as a trigger to instigate more objective monitoring of community response.

Annoyance Surveys: An example of an odour annoyance survey questionnaire is contained in Appendix A. The potential for odour problems is higher, when odour-emitting industries are surrounded by urban, or semi-urban populations. In these cases, population annoyance surveys are recommended for establishing whether or not the chronic or acute effects of the odour impacts are significant.

Odour Diaries: Notes on the completion of odour diaries and an example of a diary sheet is contained in Appendix B. On occasions where a few premises or residential dwellings are affected by industrial odours, a reliable measure of population annoyance is not possible due to lack of people. However, direct monitoring of the community can be achieved using an odour diary type programme in conjunction with an independent source of wind direction monitoring.

Olfactometry: Should an industrial site have odour emission limits set as conditions of an air discharge consent, then these emission rates could be checked using olfactometry to assess whether these comply. If emissions have increased substantially since granting the consent, then a technical review of the process and controls could be instigated.

Appropriate Actions: If the monitoring and assessment programme indicates that normal odour emissions are causing significant chronic adverse effects, then the appropriate response would be the completion of a technical review whose detail is consistent with the scale of the activity and sensitivity of the receiving environment. For some operations it is reasonable to implement odour control measures, monitor the community response and implement further measures if needed (trial and error approach). In other circumstances this approach may involve too much financial risk, or unacceptable impacts on the community. In this instance the cost of odour measurement and dispersion modelling may be justified for assessing the cost and benefits of odour reduction options more carefully.

Ultimately, a company should be given sufficient time to assess the options, cost benefits and consult with the council and community before committing to an action plan for reduction of normal emissions from the site.

7.3.2 Acute Odour Effects (Section 3.2)

Acute odour effects are generally associated periodic or infrequent odour emission levels that create short-term intense impacts. These scenarios are typical for activities such as land-spreading wastewater and slurry, by-products rendering, wastewater treatment ponds, intensive livestock farming operations. Consequently, attempts by enforcement officers to identify the cause of a specific odour event, and requirements of the company to take action to rectify the problem is an effective regulatory/management response.

Complaints: Beyond the boundary observations by council officers in response to odour complaints will always be a primary tool for assessing acute odour effects. However, additional and more detailed information is probably required to enable corrective action to be enforced.

Annoyance Surveys: If the acute odour events do reoccur then an annoyance survey should effectively the extent of adverse effects, given that the potentially effected population is sufficiently large for this approach (ie. approximately 50 people or more). See Appendix A for an example questionnaire.

Odour Diaries: In this instance odour panels within the community can be used to provide a record of specific intense odour events, which is more systematic than complaint records. Panellists can record the time and duration of an event as well as describe their behavioral responses to specific events that occur. When odour impacts are very infrequent, and capable of causing significant acute effects, then an odour diary programme may be more effective than an odour annoyance survey for monitoring the short-term effects upon the community (see Appendix B).

Olfactometry: The approach discussed by Huey[12] in 1960 may be relevant, as it appears that the scentometer was used to confirm the occurrence of relatively severe events of ambient odour. However, the approach is not practical unless studies are conducted to develop the relationship between concentration of ambient odour and short term responses. Given the expense involved in conducting odour sampling and measurement, this approach is not recommended.

Appropriate responses: Because acute odour emissions generally result from process upsets, failure of equipment can be readily diagnosed, then requiring improved management is an effective regulatory approach. Furthermore, the imposition of method-based consent conditions can also be effective. Such conditions also allow compliance to be reviewed by an enforcement officer in response to an odour event. Therefore the main focus is to identify the causes of the acute odour emissions and how these can be better avoided.

If monitoring shows that acute odour effects have occurred, and causes identified, then a review of the environmental management system is justified. The results of the review should be improved management procedures and engineered systems for reducing the risk of uncontrolled odour releases. Note that this response is significantly different to the approach discussed in section 7.3.1 for reducing chronic odour effects. In this case the management system and general contingency measures are the key to avoidance. There is also little scope to utilise olfactometry for assisting with the review process, unless the company requires performance testing of proposed new odour control technologies.

7.4 Assessment of Odour Effects

Tables 3 and 4 provide such recommended approaches for the assessment of chronic and acute odour effects from new and existing industrial sites. An explanation of the rationale is provided below.

7.4.1 Odour Concentration Guidelines

There is currently an insufficient number of ofactometry/dispersion modelling versus community response investigations to allow for routine use of this approach. The limited evidence that is available to date indicates that a 99.5 percentile concentration value of 10 ou/m^3 (certainty threshold) using European methods would be an acceptable level of odour impact in many existing circumstances. Nevertheless this should only be used as a further indicator of the potential impacts of existing industrial odour emissions at this time, but not the primary indicator. Furthermore it is reasonable to argue for a lower guideline when assessing new proposed activities given the greater uncertainty in the modelling assessment and lower tolerance to any new odours within a community.

The proposed use of the 99.9 percentile concentration of 5 ou/m^3 (certainty threshold)[6] scaled by various peak-to-mean ratios is considered to result in a reasonable assessment guideline for proposed area sources establishing close to large metropolitan residential areas (ie. 99.9 percentile concentration of 2.0 ou/m^3, certainty threshold). However the very low values that are required for stack sources of (ie. 99.9 percentile concentration 0.2 to 0.8 ou/m^3, certainty threshold) is considered to be overly conservative even for proposed new stack sources. Therefore for proposed new stack sources a further safety factor of 2 to 5 is recommended; resulting in an 99.9 percentile concentration guideline of 2.0 to 5.0 ou/m^3 (certainty threshold, 1-hour average).

Where circumstances do justify essentially "no odour" then the use of olfactometry/dispersion modelling odour assessments may still not be the most reliable assessment approach. This is because the aim of the assessment is relatively simple; that is to indicate the certainty that "no odour" will occur at the site boundary. In this instance there is little need to consider the FIDOL factors, but rather it is necessary to assess the ability of the process and best practical control technologies to reliably eliminate odour beyond the site boundary. This requires a focus upon performance and reliability of proposed engineering systems (ie. BPO considerations).

Finally, the proposed odour modelling guidelines provide a useful starting point, however any revision of these in the longer term should follow a scientifically robust methodology that includes the direct measurement of the community annoyance.

Recommendation 3: Development of Future Concentration Guidelines

Any future development of odour concentration guidelines are based on the measurement of odour exposure and subsequent extent of community annoyance via standardised olfactometry methods and population annoyance survey protocols.

7.4.2 FIDOL Factors

The FIDOL factors are fundamental concepts that are often quoted. However, in practice they are difficult to establish, as this requires a well-trained community odour diary panel. Even if some reliable data can be obtained, there is no indication of the criteria (analogous to a numeric odour guideline) the results would be assessed against. It is only practical to assess the effects of the FIDOL factors by conducting a population annoyance survey.

7.4.3 Population Annoyance Surveys (Appendix A)

The population odour annoyance survey method is described by Miedema[18] and the German Guideline for assessing odour annoyance[30] and has been already used with some success in are number of regions in New Zealand[21]. It is recommended that this approach be adopted as the primary method for assessing whether or not the effects of odour emissions are objectionable or offensive.

The criteria for deciding whether or not objectionable or offensive effects are occurring are indicated by the survey results have also been defined in Section 7.2.1 above.

Finally, where it is not possible to conduct an annoyance survey, then the use of community odour diaries, or olfactometry/dispersion-modelling assessments are possible alternatives.

7.4.4 Community Odour Panels (Appendix B)

Community odour panels can be used to keep diary records of odour impacts for assessment of FIDOL factors associated with chronic odour effects, or for specifically assessing the short-term behavioral response of the community to acute odour effects.

As discussed above, it is difficult to assess the significance of FIDOL information generated by diaries, except to try and gauge the likelihood of compliance with an accepted odour concentration guideline value. This can be indicated from the results by establishing the percentage of time that recognisable or annoying odours occur. To assist with this assessment, it would be reasonable to assume that perceptions of recognisable or annoying odours in the real environment (this can have a much lower concentration threshold than "offensive") would equate to at least 10 ou/m^3 (detection-based and 1-hour average) as generated by dispersion model predictions of European based odour concentration data[5,6].

7.4.5 Dispersion Modelling

The calculation of percentile odour concentrations requires the use of an atmospheric dispersion model, source emission data and meteorological data. Of these three components the dispersion model is generally the most robust link in providing a reliable prediction. In practice, simple gaussian dispersion models such as AUSPLUME[20] provide very good predictions of percentile odour concentrations given sufficiently accurate odour emission and meteorological inputs. The evidence of this is clear from the development of consistent relationships between modelling results and population annoyance levels[10,19,21].

When calculating a percentile odour concentration it is important to have a robust model that "on average" makes the correct prediction of odour concentrations when accumulating the results over 8760 hours (ie. one year) of meteorological records. It is not important that a model like AUSPLUME will make significant errors for some of the hourly concentration predictions, as long as this error has a random nature. This is typically the case, so the final results after 8760 calculations of hourly varying concentration is a reasonably stable prediction of 98.0 and 99.5-percentile concentration values.

There are two common misconceptions regarding the necessity of more complex numerical based dispersion models. Firstly, that they can provide a more accurate prediction and secondly that shorter averaging time frames need to be considered. Numerical models that utilise fundamental equations of mass and energy conservation may be more subject to "consistent error" in some circumstances, and as a result can produce large deviations from the true percentile concentration following the processing of a full year of hourly meteorological records. In this respect, simple gaussian models can be more stable.

Regarding the need to consider short-term odour concentrations for periods of a few seconds or so, the research to date has demonstrated that population annoyance can be effectively correlated with hourly average concentration data. For this reason concentration guidelines for odour should adhere to the one-hour averaging time frame, as the only successfully completed studies involve one-hour average predictions.

The situation where more complex dispersion models have a clear advantage over simple gaussian models involves the consideration of specific meteorological phenomena or events. This ability lends itself well to the prediction of acute odour impacts, which result from a complex meteorological or terrain effect., or consideration of odour impacts during calm conditions where diffusion-based transfer of odour is more dominant than convective transport through the air. Gaussian-Puff models can simulate this process reasonably well.

7.4.6 Control Technologies/ Best Practical Option

This report has avoided any detailed discussion of odour control technologies for a number of reasons. The enactment of the RMA and subsequent repeal of section 1(c) of the fourth schedule of the Act are indicative of the shift from method-based to effects-based regulation. Furthermore, the definition of what is the best-practical option (BPO), or best practical technology in any one circumstance can become involved and subjective. Therefore the requirement for the use of BPO to minimise odour emissions is not an effective form of consent condition and neither is it recommended as a bench-mark to use when assessing the environmental performance of an industrial facility.

For consistency with effects-based regulation, proposed or existing odour control technologies should be assessed in regards to the level of residual environmental-effects that can be expected. However, the compliance, or otherwise with the varying views of experts in regards to what constitutes BPO, should not be a mandatory requirement. It is mainly from an industry perspective that control technology reviews are an important consideration for odour management.

8 SUMMARY

8.1 General

The aim of this report is to provide the basis for a reasonable and consistent approach for conducting odour assessments and monitoring practices as applied to industrial facilities. Currently there is uncertainty in predicting the level of odour control that may be required to comply with some existing or proposed regional policies and guidelines relating to odour. There needs to be a consistent approach for screening appropriate case studies to ensure that these guidelines are validated and revised effectively.

8.2 Objectionable or Offensive Odours

The basis of this report and recommendations is that the legal meaning of *objectionable or offensive odours* is less important than the definition of when adverse odour effects on the community occur. It is therefore important to have a sound technical basis for defining when such odours are likely to cause, or have caused adverse effects on the community. This is derived in part, from the social sciences field.

There has been a tendency in the past to rely on the legal profession and case law decisions to assist with interpretations of objectionable or offensive odours. The change in focus to considering when adverse effects occur shifts the debate towards a more technical framework, which is considered to be more consistent Section 17 of the RMA 1991.

8.3 Development of Concentration Guidelines

In Western Europe concentration standards or guidelines are increasingly based upon empirical social research. However, in Australia and New Zealand a more theoretical approach has been adopted in recent times. The approach relies upon untested theories and assumptions that have been largely postulated by the physical/chemical and engineering science professions. The assumptions that are considered to have a doubtful basis including, the existence of a typical odour annoyance-threshold concentration and the applicability of olfactometer-based annoyance ratings to community perceptions. In addition to the limitations in the model used to develop odour concentration guidelines, the impact of different olfactometry protocols upon the significance of odour concentration data has not been accounted for.

Future odour guideline revisions need to follow a more empirical and scientifically robust approach.

8.4 Chronic and Acute Effects

This report defined chronic and acute odour effects as separate types of adverse odour effect. The rationale for making the distinctions is based upon the consistent differences between the causes of each type of odour effect, the temporal distribution of odour impacts and the substantially different management and regulatory strategies required in each case for effective control. Ultimately, the ability to distinguish between these two types of odour effect should allow for more rational and effective assessment approaches, and appropriate regulatory responses.

There is a tendency to look towards legal arguments and developing case law for guidance on odour management issues. However, it is clear that the legal profession needs a more technical and scientific basis to assist their decision-making regarding potential adverse odour effects. The specification of chronic and acute types of adverse odour effect is considered to be a necessary step to providing that basis.

8.5 Population Annoyance

The primary approach that is recommended for assessing and monitoring odour effects is the population annoyance survey and associated maximum allowable annoyance criteria. The advantages of this approach include its ability to:

- account for varying community acceptance of odour impacts;
- be insensitive to unreasonable minority views; and
- provide a basis for developing acceptable odour concentration guidelines.

Defining an objective basis for assessing the potential for chronic or acute odour effects and distinguishing between the two has helped rationalise and simplify the monitoring and assessment approaches that are recommended.

Finally, the use of "population annoyance" criteria provides the only opportunity for an objective assessment of whether or not odour impacts from industry are causing "objectionable or offensive" effects. This has been a long time desire for both industry and regulatory bodies.

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TABLES

Date	Olfactometer Type	Basis for Ambient Criteria	Odour Concentration Standard	Estimated Equivalents to (OU_{Europe}/m^3)	Probable Nature of Impact Being Controlled
1960	Scentometer operated in the field (non standardised method)	Comparing observations/experiences downwind of odour sources with measured values made at the same time, and community responses	7 D/T_{SCENT}	>100	Offensive odour event
1980	Panel of eight in a laboratory using yes/no response method (non standardised)	Hedonic ratings by panellists of the diluted sample offensiveness at the olfactometer laboratory	5 OU_{WSL}/m^3	10 to 25	No odour or slight momentary detection
1998	Butanol calibrated panel, Forced choice dynamic dilution laboratory (European standard)	As above	5 OU_{Europe}/m^3	5	No odour or slight momentary detection

D/T_{SCENT} = Dilution to Threshold Measurement using the Scentometer described by Huey et al[12]

OU_{WSL}/m^3 = Dilution to Threshold Measurement using the Warren Spring Laboratory Olfactometer[14]

OU_{Europe}/m^3 = Dilution to Threshold Measurement using CEN or Dutch standard methods for olfactometry[6]

TABLE 1: Historical Summary of Methods for Developing Odour Concentration Guidelines

Effect of Odour Emissions	Monitoring Tools	Assessment Criteria	Appropriate Actions
Chronic Effects (ie accumulated annoyance over time due to repeated low intensity odour impacts due to normal and continuous emissions from defined and consistent processes)	***Complaint records*** *– both urban and isolated areas* *– complaints should be validated by Council Officer observation or at least from wind direction records*	***Confirmation of recognisable odour by Council Officer*** that can not be attributed to non-compliance with method based permit conditions	Used as a trigger for more robust monitoring of community response
	Odour Diaries & Weather Monitoring *– isolated areas with low population densities*	***Cumulated hours of impact*** and ***FIDOL factors*** with guidance from percentile odour guideline value.	1. Technical Review (by Company) - Existing controls - emission reduction options 2. Cost-Benefit Analysis(Company) - BPO - Olfactometry/modelling - Annoyance predictions 3. Report Back to Council 4. Agreed Plan of Action 5. Monitor Improvements & Effects
	Odour Annoyance Survey *– Urban and semi-urban areas*	***No official guidelines exist, although*** 20%-at least annoyed is recommended	
	Olfactometric Quantification of Source Odour Emissions – New sites with defined and consistent discharges, or those sites that primarily relied upon the olfactometry/modelling approach for obtaining a resource consent.	***9.1.1.1 Allowable Emissions Based upon a Percentile Odour Standard*** #a one-hr average standard of 10 ou/m^3 (certainty threshold) if an existing or new facility, or lower value (ie. 2 ou/m^3, certainty) if new facility is proposed in a location that is close to urban areas.	
Acute Effects (ie short term offensive impacts due to unstable or highly variable emissions that occur on occasions)	***Incidents of Odour Complaint*** *– both urban and isolated areas*	***Confirmations of recognisable odour by Council Officer***	Check for compliance with any method based consent conditions
	Odour Diary records of "specific event related responses" from the public	***No narrative guidelines exist, but results can be used as evidence of adverse effects in conjunction with an officers own observations***	1. Identification of Causes 2. Management System Review 3. New Contingency Measures 4. Report Back to Council 5. Agreed Plan of Action 6. Monitor Improvements & Effects

TABLE 2: Monitoring, Assessment Criteria and Responses

Assessment Tools	Assessment Criteria
Council and Company Complaint Records Complaints should be validated by Council Officer observation or at least from wind direction records.	***Level of Complaint and recent trends*** This is used to indicate the detail of assessment required, eg. minimal public submissions and complaint history regarding odour issues would justify a BPO style assessment only.
Technical Review of Process, Mitigation Measures and Method of Discharge Mandatory for all discretionary activities	***Acceptable Level of Risk for System Failure***
Odour Diaries & Weather Monitoring Data Isolated areas with low population densities	***Cumulated hours of impact*** and ***FIDOL factors*** With guidance from percentile odour guidelines
Odour Annoyance Survey Urban and semi-urban areas	***Guideline for Odour Annoyance*** ***"20% at-least annoyed"***
Olfactometry , Meteorological Monitoring and Dispersion Modelling – New Industrial Sites or – Site Expansions – for Processes with defined and consistent discharges to air. **(Not appropriate for processes whose odour emissions can not be practically measured and otherwise exhibit high short term peaks)**	***9.1.1.2 Percentile Odour Concentration Guideline*** # A 1-hr average standard of 10 ou/m^3 (certainty threshold) if an existing or new facility, or lower value (ie. 2 ou/m^3, certainty) if new facility is proposed in a location that is close to urban areas.
Olfactometry , Meteorological Monitoring and Dispersion Modelling Optional approach for Existing Sites with defined, consistent discharges.	***9.1.1.3 Percentile Odour Concentration Guideline*** Use the 1-hr average value of 10 ou/m^3 (certainty threshold) purely as a crosscheck upon conclusions drawn from community response data, management system review and general site observations.

TABLE 3: Assessment of "Chronic" Adverse Effects

Assessment Tools	Assessment Criteria
Records of Odour Complaint Incidents	***Confirmations of recognisable odour by Council Officer***
Technical Review of Process, Mitigation Measures and Nature of the Discharge This is the primary tool for assessing the extent of risk for an abnormally large release of odours that could cause an acute odour incident.	***Acceptable Level of Risk for System Failure***
Odour Annoyance Survey Urban and semi-urban areas	***Guideline for Odour Annoyance*** ***"20% at-least annoyed"***
Odour Diaries & Weather Monitoring Data	Significant occurrence of specific behavioral responses within the population
Predicted Worst Case Odour Concentration Impacts[#] Direct sampling results or using worst case odour emission data, source characteristics, dispersion model and screening meteorological data. ***[#] This is the old "beyond the boundary measurement approach" reported by Huey (1960)[12], but is not preferred due the lack of supporting dose-response information.***	***Fixed Limit Odour Standard (ou/m^3)*** Limit would need to correspond to a concentration where the effects on the exposed community could be expected to breach the ***Narrative Standard for Acute Odour Incidents*** (section 7.2.2). No such criteria are currently available, although it is estimated from the reports of Huey (1960)[12] that short term peak concentrations (of an one hour or less) would need to exceed several 100 ou/m^3 (detection threshold).

TABLE 4: Assessment of "Acute" Odour Effects

APPENDIX A

Example of Annoyance Survey Questionnaire

EXAMPLE OF ODOUR ANNOYANCE SURVEY

Residential telephone questionnaire

PLEASE NOTE THAT FOR MOST OF THE QUESTIONS YOU ONLY ENTER THE CODES

INTRODUCTION

READ "Good evening, my name is ……from Aurora Environmental Ltd, an independent environmental research company. "We are currently carrying out research looking at environmental issues in your local community. Could I please speak to a person in your household who is over 18 years old, and whose birthday it is next?"

ONCE CONTACT IS ESTABLISHED REINTRODUCE SELF IF NECESSARY AND READ…

"The survey only takes five minutes to complete and all your responses will remain totally confidential. Would now be a convenient time, or may I call back later?"

IF YES, CONTINUE

IF NO, MAKE TIME TO CALL BACK, AND NOTE ON SUMMARY SHEET

IF REFUSED THANK AND CLOSE, AND NOTE ON SUMMARY SHEET

IF ASKED WHO THE SURVEY IS FOR, READ …" We need to keep the research as objective as possible, so I can't tell you that straight away. However, I promise that I will tell you at the end of the questionnaire".

IF REFUSED, THANK AND CLOSE, AND NOTE ON SUMMARY SHEET
IF AGREE, CONTINUE (NOTE ON SUMMARY SHEET).

1. **What do you consider to be the main environmental issues facing your local community at present if any? By environmental issues I mean things that affect the physical environment like water quality and pollution.** [DO NOT READ LIST, CODE ALL MENTIONS]

1. Air pollution
2. Noise
3. Water pollution
4. Drinking water quality
5. Sprays / pesticides / herbicides etc.
6. Motor vehicle emissions
7. Other (specify)
8. Don't know **(GO TO Q2)**
9. None **(GO TO Q2)**

1b Of the issues you have mentioned, which do you feel is the most important to your community? [DO NOT READ LIST, CODE ONE ONLY]

1. Air pollution (general)
2. Air pollution from industry
3. Noise (general)
4. Noise from industry
5. Water pollution (general)
6. Water pollution from industry
7. Drinking water quality
8. Sprays / pesticides / herbicides etc.
9. Motor vehicle emissions
10. Other (specify)

2. During spring, do you suffer any effects from plant pollen such as hayfever or allergies?

1. Yes **(CONTINUE)**
2. No **(GO TO Q3)**
3. Refused **(GO TO Q3)**

2b. How much of a problem is this for you? [READ AND ROTATE ORDER]

1. Not very serious
2. Somewhat serious
3. Very serious

2c. Does this problem require you to take any forms of medication?

1. Yes
2. No
3. Sometimes
4. Always

3. How often do you notice noise from any local industries? [READ & ROTATE ORDER]

1. All the time **(CONTINUE)**
2. Often
3. Sometimes
4. Seldom
5. Never **(GO TO Q4)**

3b. To what degree does this noise annoy you? You might want to write this scale down. Do you find this noise …. [READ SCALE & ROTATE ORDER]

1. Definitely not annoying
2. Very little annoyance
3. Little annoyance
4. Some annoyance
5. Annoying
6. Quite annoying
7. Very annoying
8. Extremely annoying

3c. What is the most common source of this noise? [DO NOT READ OUT]

1. Industry
2. Parties
3. Traffic
4. Other (specify)

4. How often do you notice an odour or smell from industry in or around your home? [READ AND ROTATE ORDER]

1. All the time **(CONTINUE)**
2. Often
3. Sometimes
4. Seldom
5. Never **(GO TO Q5)**

4b. To what degree does this odour annoy you? Do you find this odour is … [READ SCALE AND ROTATE ORDER]

1. Definitely not annoying
2. Very little annoyance
3. Little annoyance
4. Some annoyance
5. Annoying
6. Quite annoying
7. Very annoying
8. Extremely annoying

4c. What do you think is the most common cause of this odour? [DO NOT READ OUT]

1. Fertiliser factory
2. Wool scour
3. Coffee roasting
4. Other industries
5. Traffic
6. Other (specify)

4d. Can you describe **this odour?** [DO NOT READ OUT]

1. Do not know
2. Fishy
3. Chemical
4. Coffee roasting
5. Chocolate
6. Coal fire
7. Bitumen
8. Meat
9. Other (specify)

4e. Can you specify the plant **that causes this odour?** [DO NOT READ OUT]

1. Do not know
2. Sealords
3. Ravensdown
4. Cadbury
5. Cerebos Gregg's
6. Palmers
7. Other (specify)

5. Finally, just a few short questions to finish. What is your occupation?

1. Legislation, administration, management
2. Professional
3. Technical
4. Clerical
5. Sales/service
6. Agriculture/fishery
7. Trade
8. Plant/machine operators
9. Elementary (unskilled)
10. Home maker
11. Unemployed
12. Retired
13. Study

6. How old are you?

1. 18-20
2. 20-25
3. 25-30
4. 30-35
5. 35-40
6. 40-45
7. 45-50
8. 50-55
9. 55-60
10. 60-65
11. 65-70
12. 70-75
13. 75-80
14. 80-85
15. 85-90

7. Which street do you live in?

IF RESPONDENT REFUSES ASSURE THEM THAT THEIR PERSONAL DETAILS WILL NOT BE DIVULGED

8. Code gender

1. Male
2. Female

Thank you for your time. This research has been conducted on behalf of ********. If you have any queries you can contact ********** on ph **********. My name is .....……**

APPENDIX B

Notes for Odour Diary Panellists and Example of Record Sheet

ODOUR DIARY MONITORING NOTES

Thank you for agreeing to become an odour diarist and help ****** monitor the odours in the ******* area. The odour diary enclosed is for the purpose of developing a full and accurate recorded history and trend of odour observations, therefore it is important that the diary is as accurate as possible.

You will note in the diary that there are seven factors to fill in for each odour event. These are the date, time, duration, continuity of odour events, odour character, and odour strength/intensity and wind conditions. The level of detail, which will typically be required, is discussed below:

Odour Events: It is always difficult to exactly define when repeated odour events within the same day are part of the same event, or whether separate records are required. As a general rule, when the odour keeps occurring (ie is intermittently occurring over an extended period of time) and for the same wind conditions then this can be recorded as a single event with intermittent impacts. This avoids you having to make numerous diary entries for the same day.

Alternatively you may experience a few different odour events throughout the same day where the odour was persistent (always present) for an hour or less and then disappeared for several hours before occurring again. These situations should be recorded as separate events.

As general rule, you should record odour events on the same day as separate diary entries if –

(a) the time between the events is much longer than the actual time the odours are present; or

or

(b) there had been a significant wind change between the different observations of odour.

Location: Because we need to quantify the extent of source of odour impacts at your residential location we ask that you restrict your recorded observations to those experience at home, or some other fixed location where you consistently spend a significant amount of time.

FILLING IN THE RECORD SHEET

Date & Time of Odour Event: The date and time of day when the odour was first noticed and when it ceased must be recorded. If for example the odour was noticed first in the morning and it persisted for most of the day, then this can be recorded as a single event.

Duration of Odour Event: It is very important to provide clear details regarding the total time that odour was present during each event you have recorded. This information allows us to estimate the percentage of time that odour impacts occur, which is central to the assessment of the diary results. Note the duration needs to be recorded in **HOURS** or otherwise a time range **eg 8:30 am to 2.30 pm**

Continuity of Each Odour Event: It is important to consider whether or not the odour event was "continuous" or "intermittent" during the time period that you have recorded under "time". Simply tick the column of options that most resembles the specific odour event. The options to select from include:

- continuous; or
- most of the time; or
- 50% of the time; or
- infrequently

Character of Odour: You will need to distinguish between the various characters or type of odour that you experience. You could try to relate the odour to a something commonly understood, such as a strong mouldy smell, a blocked drain smell, a cooking meat smell, a sulphurous, mothball smell, a wet wool smell, a burning grease smell etc

Source of Odour: Based upon the character of the odour and wind conditions, record what you consider to be the source of the odour, or whether you can not identify the likely source.

Strength of Odour Event: This record relates only to the intensity or strength of the odour and should be rated as follows:

- faint odour; or
- mild strength odour; or
- medium strength odour; or
- strong odour; or
- very/extremely strong odour;

Wind Conditions: General wind direction, e.g. blowing from the north-west, and hot summers day or cold overcast day with southerly winds etc should be record followed by the approximate wind strength as follows:

- still/calm; or
- light breeze; or
- medium breeze; or
- moderate wind; or
- strong wind;

Odour Diary Record Sheet

Name:	**Location of Observations:**
Month:	

DATE	**Time** (am or pm)	**Odour Event Duration** (hrs)	**Continuity of the odour for this event**				**Character of Odour**	**Likely Source of Odour**	**Strength of Odour**	**Wind Direction**	**Wind Strength**
			continuous	most of the time	< 50% of the time	intermittent					
			(tick one)	(tick one)	(tick one)	(tick one)					