Technical Notes

Draft Policy: Assessment and Management of Odour from Stationary Sources In NSW

January 2001

NSW EPA
ENVIRONMENT PROTECTION AUTHORITY

Draft Policy

These Technical Notes accompany *Draft Policy, Assessment and Management of Odour from Stationary Sources in NSW* (published in a separate booklet).

What do you think about the Draft Policy?

Please send written comments on these Technical Notes and the Draft Policy to:

Director Air Policy
Environment Protection Authority
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Sydney South NSW 1232

Closing date for receiving submissions is **Monday 30 April 2001**.

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Published by:

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ISBN 0 7313 2757 8
EPA 2001/1
January 2001

Printed on recycled paper

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1 Identifying and classifying odour sources

Activities scheduled under the *Protection of the Environment Operations Act 1997* (POEO Act) that may generate odour can generally be grouped into two categories, as presented in Table 1.1.

The **point source** category broadly contains activities that involve stack emissions of odour. Generally these can be relatively easily controlled using waste reduction, waste minimisation and cleaner production principles or conventional emission control equipment.

The **diffuse source** category lists activities that are generally dominated by area or volume source emissions of odour, which can be more difficult to control (e.g. intensive agricultural activities).

Table 1.2 sets out which industries could assess odour impacts against the ground-level concentration (glc) criteria and/or the odour performance criteria, discussed later in chapters 2 and 3 of this document. Both criteria may apply to some industries.

Tables 1.1 and 1.2 have been included as a guide in order to explain the need to deal with the complexities of diffuse and point sources, specific pollutants and overall odour impacts. In practice, each odour impact assessment will entail determining which odorous sources are point or diffuse releases and whether individual or complex odours are being emitted, taking into account site-specific factors.

Table 1.1 Nature of odour sources for POEO scheduled activities

Industry	Point source	Diffuse source
Agricultural produce industries	X	X
Bitumen pre-mix or hot-mix industries	X	–
Breweries or distilleries	X	–
Chemical industries or works	X	–
Chemical storage facilities	X	–
Composting and related reprocessing or treatment facilities	X	X
Contaminated soil treatment works	X	X
Drum or container reconditioning works	X	–
Electricity generation works	X	–
Livestock intensive industries	–	X
Livestock processing industries	X	X
Mineral processing or metallurgical works	X	X
Paper, pulp or pulp products industries	X	X
Petroleum works	X	–
Sewage treatment systems	X	X
Waste facilities	X	X
Wood or timber milling or processing works	X	–
Wood preservation works	X	–

Table 1.2 Applicability of ground-level concentration criteria and odour performance criteria to scheduled activities

Industry/scheduled activity	Ground-level concentration criteria	Odour performance criteria
Agricultural produce industries	X	X
Bitumen pre-mix or hot-mix industries	X	–
Breweries or distilleries	X	X
Chemical industries or works	X	X
Chemical storage facilities	X	–
Composting and related reprocessing or treatment facilities	–	X
Contaminated soil treatment works	X	–
Drum or container reconditioning works	X	–
Electricity generation works	X	–
Livestock intensive industries	–	X
Livestock processing industries	X	X
Mineral processing or metallurgical works	X	–
Paper, pulp or pulp products industries	X	X
Petroleum works	X	–
Sewage treatment systems	X	X
Waste facilities	X	X
Wood or timber milling or processing works	X	–
Wood preservation works	X	–

2 Ground-level concentration (glc) criteria

Table 2.1 Ground-level concentration (glc) criteria

Pollutant	glc [a]	
	ppm [d]	mg/m^3 [e]
Acetaldehyde [b]	0.042	0.076
Acetic acid [b]	0.20	0.50
Acetone [b]	20	48
Acrolein	0.0033	0.0083
Acrylic acid [b]	0.094	–
Acrylonitrile	0.067	0.15
Ammonia	0.83	0.6
Aniline	0.17	0.63
Asphalt (petroleum) fume	–	0.17
Barium (soluble compounds)	–	0.017
Benzene	0.033	0.10
Beryllium	–	0.00007
Benzyl chloride [b]	0.0094	0.047
Biphenyl	0.0067	0.033
Bromochloromethane	6.7	35
Bromoform	0.017	0.17
Bromotrifluoromethane	33	203
1,3-Butadiene [b]	0.45	1.0
n-Butanol [b]	0.3	0.9
Butyl mercaptan [b]	0.004	0.012
Carbon black	–	0.1
Carbon disulphide [b]	0.042	0.13
Carbon tetrachloride	0.17	1.1
Chlorine	0.033	0.1
Chlorine dioxide	0.003	0.01
Chlorobenzene [b]	0.042	0.20
Chloroform	0.33	1.59
Chloromethane	3.3	7.0
Chromic acid, chromates as CrO_3	–	0.0017
Chromium, soluble chromic and chromous salts as Cr	–	0.017
Copper fume	–	0.0067
Copper dust and mists	–	0.033
Cotton dust (raw)	–	0.0067
Crotonaldehyde	0.067	0.2
Cumene [b]	0.008	0.039
Cyanide (as CN)	–	0.2
Cyclohexane	10	35
Cyclohexanol	1.7	6.7
Cyclohexanone [b]	0.12	0.48
Diacetone alcohol [b]	0.28	1.3
o-Dichlorobenzene	1.7	10
1,2-Dichloroethylene	6.7	26.3
1,2-Dichloroethane	1.7	6.7

Pollutant	glc [a]	
	ppm [d]	mg/m^3 [e]
Dichlorvos	0.0033	0.033
Diethylamine [b]	0.02	0.06
Dimethylamine [b]	0.0094	0.017
Dinitrobenzene (all isomers)	0.005	0.033
Dinitrotoluene	–	0.050
Dusts [c]	–	0.33
Diphenyl ether [b]	0.02	0.14
Epichlorohydrin	0.067	0.25
Ethanol [b]	2.0	3.8
Ethanolamine	0.10	0.20
Ethyl acetate [b]	6.3	22.1
Ethyl acrylate [b]	0.0002	0.0008
Ethylbenzene	3.3	14.5
Ethyl butyl ketone	1.7	7.7
Ethyl chloride	33.3	86.6
Ethylene glycol (vapour)	3.3	8.7
Ethylene oxide	0.03	0.05
Fluorine	0.033	0.067
Formaldehyde	0.033	0.05
n-Hexane	1.67	6.0
2-Hexanone	0.83	3.3
Hydrogen chloride	0.2	0.2
Hydrogen cyanide	0.3	0.4
Hydrogen sulphide [b]	0.0001	0.00014
Iron oxide fume	–	0.17
Mercury (organic)	0.00003	0.0003
Mercury (inorganic)	–	0.0017
Magnesium oxide fume	–	0.33
Maleic anhydride	0.0083	0.033
MDI (Diphenylmethane di-iso-cyanate)	0.0007	0.007
Methanol [b]	4.26	5.5
Methyl acrylate	0.33	1.2
Methylamine [b]	0.0042	0.005
Methylene chloride	3.3	12.0
Methyl ethyl ketone [b]	2.0	5.9
Methyl mercaptan [b]	0.00042	0.00084
Methyl methacrylate [b]	0.05	0.21
α-Methyl styrene [b]	0.052	0.25
Methyl isobutyl ketone [b]	0.1	0.41
Nickel carbonyl	0.0017	0.012
Nitric acid	0.067	0.17
Nitrobenzene [b]	0.00094	0.0047
Pentachlorophenol	–	0.017

Pollutant	glc [a]	
	ppm [d]	mg/m³ [e]
n-Pentane	20	60
2-Pentanone	6.7	23.3
Perchloroethylene [b]	0.94	6.3
Phenol [b]	0.0094	0.036
Phosgene	0.0033	0.013
Phosphine [b]	0.0042	0.0056
Phthalic anhydride	0.033	0.20
n-Propanol [b]	0.03	0.075
Propylene glycol monomethyl ether	3.3	12.0
Propylene oxide	3.3	8.0
Pyridine [b]	0.0042	0.013
Silver, metal and soluble compounds (as Ag)	-	0.00033
Styrene (monomer) [b]	0.05	0.21
Sulphuric acid	–	0.033
Toluene [b]	0.17	0.65
TDI (Toluene-2,4-di-iso-cyanate)	0.0007	0.005
1,1,1-Trichloroethane	11.7	63.3
1,1,2-Trichloroethane	0.33	1.5
Trichloroethylene	1.67	9.0

Pollutant	glc [a]	
	ppm [d]	mg/m³ [e]
Trichlorofluoromethane	33.3	187
Triethylamine [b]	0.09	0.36
Trimethylbenzene (mixed isomers)	0.83	4.0
Vinyl chloride	0.033	0.1
Vinyl toluene	3.3	16.0
Welding fume (total particulate)	–	0.17
Wood dust, non-allergenic	–	0.17
Xylene [b]	0.08	0.35
Zinc chloride fume	–	0.033
Zinc oxide fume	–	0.17

a Based on consideration of toxicity unless otherwise specified.

b Based on consideration of odorous properties of the indicator.

c Other than cotton, quartz bearing, asbestiform, talc, mica, cristobalite and tridymite.

d Parts per million (volume/volume).

e Gas volumes are expressed at 25 °C and at an absolute pressure of one atmosphere (101.325 kPa).

2.1 Applying the ground-level concentration criteria

Using the criteria

These criteria should be used routinely for the design and siting of a new facility, in addition to setting point-source emission limits. In addition, these criteria should be used during the ongoing management of a facility in order to develop odour mitigation strategies and point-source emission limits that may be required. For existing facilities, the EPA will use the criteria on a case-by-case basis, in response to odour impact problems.

To quantitatively determine the frequency, intensity and duration of odours, the ground-level concentration criteria should be reported as the **100**th percentile of dispersion model predictions for Level 2 odour impact assessments and the **99.9**th percentile for Level 3 odour impact assessments. For point source discharges, stack-emission concentration limits can be included on the environment protection licence. This will help to ensure compliance with the ground-level concentration criteria.

For dispersion modelling purposes, the glc criteria should be applied at any location at or beyond the site boundary as follows:

1 Impacts for glc pollutants must be reported for an averaging period of **3 minutes**.

2 For Level 2 odour impact assessments, impacts must be reported as the **100**th percentile of dispersion model predictions.

3 For Level 3 odour impact assessments, impacts must be reported as the **99.9**th percentile of dispersion model predictions.

4 Compliance with the glc criteria is to be determined by using source emission measurements and dispersion modelling only.

5 For point sources, dispersion modelling results will be used as the basis for developing licence limit concentrations on stack discharges for glc pollutants.

6 It is not appropriate to use the glc criteria as default licence conditions for a facility.

2.2 Developing alternative ground-level concentration criteria

The following procedure (also set out in Figure 2.1) should be used for developing or modifying glc criteria for individual odorous pollutants so they are consistent with the European CEN and draft Australian Standard dynamic olfactometry methods detailed in chapter 8 of this document. (Note: before undertaking development of alternative criteria, the EPA should be contacted to ensure the proposed work would comply with this policy.)

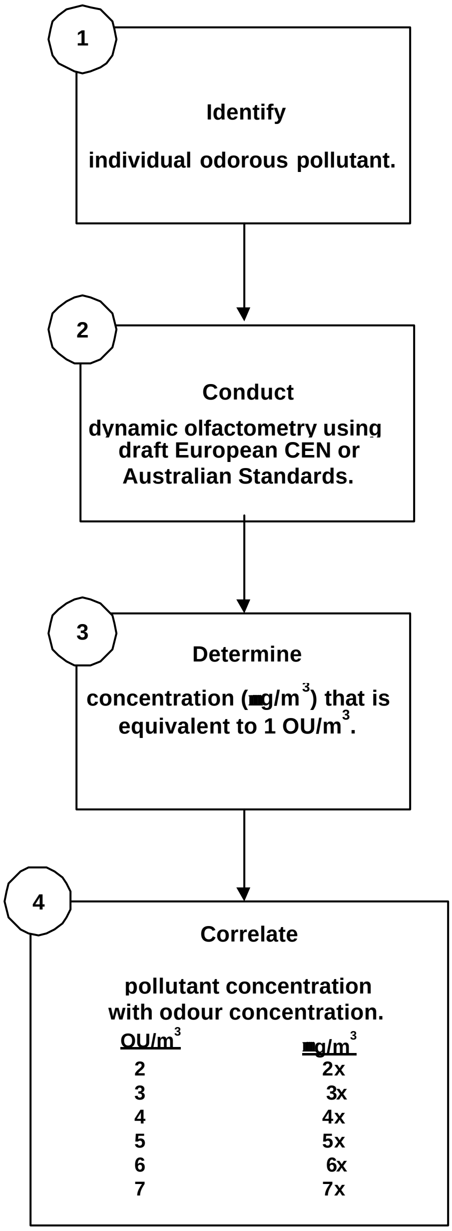
1 Identify the individual odorous pollutant that requires modified glc criteria.

2 Using known concentrations of the individual odorous pollutant, conduct dynamic olfactometry in accordance with the European CEN or draft Australian Standard dynamic olfactometry methods detailed in chapter 8.

3 Develop a correlation between the concentration (e.g. $\mu g/m^3$) and dilution factor (ie. OU/m^3) of the individual odorous pollutant. Report the concentration (e.g. $\mu g/m^3$) that corresponds with 1 OU/ m^3.

4 Determine the individual odorous pollutant concentration (e.g. $\mu g/ m^3$) that corresponds with the population-dependant odour performance criteria (ie. 2 OU/ m^3 to 7 OU/ m^3). For example, if 1 $\mu g/ m^3$ corresponds to 1 OU/ m^3, then 2 $\mu g/ m^3$ corresponds to 2 OU/ m^3 and so on.

Figure 2.1 Procedure for determining alternative ground-level concentration criteria



2.3 References

Environment Protection Authority of Victoria, 1985, *Plume Calculation Procedure, an approved procedure under Schedule E of State Environment Protection Policy (The Air Environment),* Publication 210

Streeton, J. A., 1990, *Air Pollution, Health Effects and Air Quality Objectives in Victoria*

Turner, D.B., 1994, *Workbook of Atmospheric Dispersion Estimates,* Second edition, Lewis Publishers, North Carolina

Victorian Government Gazette, Monday 6 June 1988, ‘Amendment to the State Environment Protection Policy (The Air Environment)’, No. S 45

3 Odour performance criteria

3.1 Comparing odour performance criteria used in other jurisdictions

A review of Australian and overseas odour performance criteria has been undertaken. Tables 3.1 and 3.2 list the odour performance criteria for various jurisdictions where the relevant odour legislation endeavours to manage the impacts of either offensive or nuisance odours. Managing the impacts of offensive odours is consistent with the legislative requirements of the POEO Act.

Table 3.1 Odour performance criteria used in other jurisdictions

Jurisdiction	Odour performance criteria (OU)
Manitoba[1]	2 to 7
*CARB[2]	5
**SCAQMD[3]	5 to 10
Massachusetts[4]	5
Connecticut[7, 5]	7
Kentucky[7,8]	7
Missouri[7,8]	7
Wyoming[7,8]	7
#DUAP[5,6]	5 to 8
##WRL[7]	5
Queensland[8]	5
+QDPI[9]	~ 1 to 5

* California Air Resources Board

** South Coast Air Quality Management District

\# NSW Department of Urban Affairs and Planning

\## Warren Springs Laboratory

\+ Queensland Department of Primary Industries

1 Mahin, T. D., 1997, *Using Dispersion Modeling of Dilutions to Threshold (D/T) Odor Levels to Meet Regulatory Requirements for Composting Facilities*, AWMA 90th Annual Meeting and Exhibition, June 8–13 1997, Toronto, Ontario, Canada, 97-TA35.04

2 Amoore, J. E., 1985, *The Perception of Hydrogen Sulfide Odor in Relation to Setting an ambient Standard*, Final report prepared by Olfacto-Labs for the California Air Resources Board

3 CEQA, 1993, *California Environmental Quality Act (CEQA) Air Quality Handbook*, South Coast Air Quality Management District, Diamond Bar, California

4 Leonardos, G., 1995, *Review of Odor Control Regulations in the USA*, Presentation for the New York Water Environment Federation

5 Zib, P. and Associates, 1995, *Odour Assessment Study in EIS for the Eastern Creek Green Waste Processing Facility*, Mitchell McCotter

6 Holmes, N. and Associates, 1997, *Assessment of Air Quality EIS Manual*. Draft prepared for Department of Urban Affairs and Planning, 4/2/1997

7 Warren Spring Laboratory, 1990, *Odour Control — A Concise Guide*, Stevenage, UK

8 Queensland Department of Environment and Heritage, 1994, *Interim Guidelines for Odours from New Developments*, Draft, 12 April 1994

9 Queensland Department of Primary Industries, 1989, *Queensland Government Guidelines for Establishment and Operation of Cattle Feedlots*

Table 3.2 Odour performance criteria used in other jurisdictions

Organisation	Criteria (OU/m³)	Averaging time	Source type	Percentile	Olfactometry	Threshold
NSW[10]	2.0–7.0	0.1–1 second	All	99	DAS[11]	[#]C
NSW (old)[12]	1.0	3 minute	Scheduled	99	EPA/SWB[13]	[##]G
NSW (old)[15]	2.0	3 minute	Non-scheduled	99.5	EPA/SWB	G
Queensland (draft)[14]	10.0	1 hour	All	99.5	DAS	C
Queensland (old)[15]	2.5	3 minute	Area	99.5	M6[15]	G
Queensland (old)[15]	0.5	3 minute	Wake-affected stack	99.5	M6	G
Victoria (new)	1.0	3 minute	All	99.9	DAS	C
Victoria/SA (old)[15]	1.0	3 minute	All	99.9	B2[16]	G
Victoria[17]	5.0	3 minute	Broiler chickens	99.5	B2	G
RIRDC[18]	5.0	1 hour	Broiler chickens	99.5	DAS	C

[#] certainty threshold

[##] guessing threshold

In the past it has been difficult to compare the results of odour impact assessments that have been carried out in different jurisdictions due to differences in the four key elements of the odour impact assessment methodology, namely: odour sampling technique, odour measurement methodology, dispersion model and odour performance criteria.

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10 NSW Environment Protection Authority, 1999, *Discussion Paper: Assessment and Management of Odour from Stationary Sources in NSW*

11 Standards Australia, 1999, *Air Quality — Determination of Odour Concentration by Dynamic Olfactometry*, Draft Australian Standard, Project No: EV/007-0600 and Committee Europe en de Normalisation, 1995, *Odour Concentration Measurement by Dynamic Olfactometry*, CEN TC264/WG2 Odours Final WG2 Draft prEN

12 Clean Air Society of Australia and New Zealand Inc., 1995, *Workshop Position Paper*, Clean Air (1995), Odour Special Interest Group 1st National Odour Workshop, 18–19 May 1995, Bond University, Queensland, Volume 29, No. 4

13 NSW Environment Protection Authority and Sydney Water Board, 1994, *Olfactometry*, Discussion of Draft Guidelines

14 Queensland Environmental Protection Agency, 1999, *A Procedure to Assess the Risk of Odour Nuisance from Proposed Developments*, Environmental Guidelines, Draft guideline

15 Queensland Department of Environment and Heritage, 1995, *Determination of Odour Concentration by Dynamic Olfactometry*, Laboratory Method 6

16 Victorian Environment Protection Authority, 1985, *Method B2, Odour (Dynamic Olfactometry)*

17 Department of Natural Resources and Environment, 1999, *Victorian Code for Best Practice Broiler Chicken Farms*, Draft Code for Public Exhibition, 14 July – 10 September 1999

18 Jiang, J. and Sands, J., 1998, *Report on Odour Emissions from Poultry Farms in Western Australia*, Odour Research Laboratory, Centre for Water and Waste Technology, School of Civil and Environmental Engineering, UNSW

In order to enable some meaningful comparisons to be made between the different odour performance criteria, odour dispersion modelling using AUSPLUME has been carried out for five common odour release types, which include[19]:

- area (e.g. mushroom composting facility)
- volume (e.g. naturally-ventilated broiler chicken farm shed).
- short stack (non wake-affected) and short stack (wake-affected) (e.g. metal plating plant)
- tall stack (e.g. kraft pulp and paper mill).

Four different dynamic olfactometry methods were considered, as follows:

- V EPA method B2
- QDEH method 6
- NSW EPA/SWB method
- Draft Australian or European CEN standard methods.

To convert odour units from one standard method to another, the following simplifying assumptions were made:

$OU_{\text{V EPA Method B2}} = 0.5 \times OU/m^3_{\text{Draft Australian or CEN Methods}}$ (Bardsley and Demetriou 1999)

$OU_{\text{QDEH Method 6}} = 3.5 \times OU/m^3_{\text{Draft Australian or CEN Methods}}$ (Verral 1997)

$OU_{\text{NSW EPA/SWB Method}} = 3 \times OU/m^3_{\text{Draft Australian or CEN Methods}}$ (NSW EPA and SWB 1994)

Table 3.3 summarises the results of the comparisons between the odour performance criteria that were detailed in Table 3.2, with the NSW EPA odour performance criteria. This comparison includes all the relevant adjustments for dynamic olfactometry method, averaging period, percentile compliance and source type.

Table 3.3 Summary of nose response time average, 99th percentile, equivalent odour concentrations for all scenarios

Standard				Nose response time average, 99th percentile				
OU	Time	%	Method	Area	Volume	Short stack	Wake-affected short stack	Tall stack
5	1 hr	99.5th	DAS	8.7	10.9	34.1	11.7	42.8
10	1 hr	99.5th	DAS	17.4	21.9	68.2	23.5	85.5
1	3 min	99.9th	DAS	0.97	1.5	3.2	1.1	4.0
0.5	3 min	99.5th	M6	0.24	0.23	0.61	0.21	0.89
2.5	3 min	99.5th	M6	1.2	1.2	3.0	1.1	4.5
2	3 min	99.5th	EPA/SWB	1.1	1.1	2.8	1.0	4.2
1	3 min	99th	EPA/SWB	0.7	0.6	1.8	0.6	4.1
1	3 min	99.9th	B2	1.9	3.1	6.5	2.2	7.9
5	3 min	99.5th	B2	16.6	16.4	42.6	18.6	62.3

19 Agapides, N. and Welchman, S., 2000, *Are All Odour Performance Criteria the Same?* Proceedings of the Enviro 2000 Odour Conference, 9 – 13 April 2000

A range of 2 OU/m^3 to 7 OU/m^3 (nose response time average, 99^{th} percentile, draft Australian Standard) is generally consistent with (but in some cases less stringent than) most of the odour performance criteria currently referred to by other State regulatory authorities, with some exceptions. The odour performance criteria of 10 OU/m^3 (1 hour average, 99.5^{th} percentile, CEN) and 5 OU (3 minute average, 99.5^{th} percentile, B2) are extremely lenient for all five odour source release types examined when compared to past and current practices in Australia. An odour performance criterion of 5 OU/m^3 (1 hour average, 99.5^{th} percentile, CEN) is quite lenient when applied to short and tall non wake-affected stacks. Given that odour continues to be one of the major air quality issues affecting Australian communities, recommending the use of any of these three lenient odour performance criteria is questionable.

3.2 Applying the odour performance criteria

The odour performance criteria presented in this document should be used in the absence of industry-specific odour performance criteria agreed to with the appropriate regulatory authority.

The odour performance criteria take into account the latest experience, research and approaches used by other jurisdictions worldwide, particularly where legislative requirements in relation to odour are similar to those of the POEO Act. They also take into account the extensive experience gained through assessing existing and proposed odorous facilities in NSW. The criteria are based on existing approaches and have been modified to take population density into account.

These criteria are concerned with controlling odours to ensure offensive odour impacts will be effectively managed but are not intended to achieve ‘no odour’.

Impacts from many odorous air contaminants are related to offensiveness rather than health issues. Odorous air contaminants that also have the potential to generate health-related impacts should be managed as individual pollutants and assessed against the glc criteria (see chapter 2).

Odour threshold

The detectability of an odour is a sensory property that refers to the theoretical minimum concentration that produces an olfactory response or sensation. This point is called the odour threshold and defines one odour unit per cubic metre (OU/m^3).

Offensive odour

In practice, ‘offensive’ odour can only be judged by public reaction to the odour, preferably under similar social and regional conditions. The nuisance level can be as low as 2 OU/m^3 and as high as 10 OU/m^3 for less offensive odours. Experience gained through odour assessments for proposed and existing facilities in NSW indicates that an odour performance criterion of 7 OU/m^3 is likely to represent the level below which ‘offensive’ odours should not occur (for an individual with a ‘standard sensitivity’ [20] to odours). Therefore, the policy recommends that, as a design criterion, no individual should be exposed to ambient odour levels of greater than 7 OU/m^3 [21].

20 ‘Standard sensitivity’ is defined by the Draft Australian and European CEN Standards, which require that the geometric mean of individual odour threshold estimates must fall between 20 ppb and 80 ppb for n-butanol (the reference compound).

21 Nose response time average, 99th percentile, Draft Australian or European CEN Standards.

Sensitive responses

The odour performance criteria have been designed to take into account the range of sensitivity to odours within the community and to provide additional protection for individuals with a heightened response to odours. This is achieved by using a statistical approach, which depends upon population size. As the population density increases, the proportion of sensitive individuals is also likely to increase, indicating that more stringent criteria are necessary in these situations.

Cumulative impacts

The potential for cumulative odour impacts in relatively sparsely populated areas can be more easily defined and assessed than in highly populated urban areas. It is often not possible or practical to determine and assess the cumulative odour impacts of all odour sources that may impact on a receptor in an urban environment. Therefore, these odour performance criteria allow for community expectations of amenity, for population density, cumulative impacts and anticipated odour levels during adverse meteorological conditions.

To ensure that offensive odour impacts are maintained within acceptable levels, the incremental increase in ambient odours due to emissions resulting from a facility's operations should be assessed against the odour performance criteria. Where it is likely that two or more facilities with similar odour character will result in cumulative odour impacts, the combined odours due to emissions resulting from all nearby facilities should also be assessed against the odour performance criteria.

Using the criteria

These criteria should be used routinely for the design and siting of a new facility, in addition to setting point-source emission limits. In addition, these criteria should be used during the ongoing management of a facility in order to develop odour mitigation strategies and point-source emission limits that may be required. For existing facilities, the EPA will use the criteria on a case-by-case basis, in response to odour impact problems.

To quantitatively determine the frequency, intensity and duration of odours, the odour performance criteria should be reported as the **100**th percentile of dispersion model predictions for Level 2 odour impact assessments and the **99**th percentile for Level 3 odour impact assessments. For point source discharges, stack-emission concentration limits can be included on the environment protection licence. This will help to ensure compliance with the odour performance criteria.

For dispersion modelling purposes, the odour performance criteria should be applied at the nearest existing off-site sensitive receptor (or likely future sensitive receptor), as follows:

1 Use Figure 3.1 and Equation 3.1 (below) to select the appropriate value for OU/m^3

2 For populations equal to or above 2000 people, the appropriate odour performance criteria is 2 OU/m^3. A summary of appropriate odour performance criteria for various population densities is shown in Table 3.4 below:

Table 3.4 Odour performance criteria for various population densities

Population of affected community	Odour performance criteria (OU/m^3)
Urban (≥ 2000)	2.0
500 – 2000	3.0
125 – 500	4.0
30 – 125	5.0
10 – 30	6.0
Single residence (≤ 2)[a]	7.0

[a] The average household size in Australia is projected to decline from 2.6 persons per household in 1996 to between 2.2 and 2.3 persons per household in 2021[22]. The average household size in NSW declined from 2.8 persons per household in 1991 to 2.7 persons per household in 1996[23]. Estimates predict that the average household size in NSW will decline to approximately 2.5 persons per household in 2004.

Consistent with Australian Bureau of Statistics figures, an average household size of 2 (with rounding) has been chosen for a single residence for generic purposes only. However, when assessing odour impacts at a single residence, it is appropriate to determine the number of people residing in the household and apply the relevant odour performance criterion in accordance with Figure 3.1 and Equation 3.1.

3 OU/m^3 is expressed as 'the highest dilution factor at which the sample has a probability of 0.5 of eliciting, with certainty, the correct perception that an odour is present'.

4 Impacts in OU/m^3 are for an averaging period of **nose response time** (ie. approximately one second).

5 For Level 2 odour impact assessments, report impacts as the **100**th percentile of dispersion model predictions. For Level 3 odour impact assessments, report impacts as the **99**th percentile of dispersion model predictions.

6 Use Equation 3.1 to determine the odour performance criterion applicable to a particular population density:

Equation 3.1

$$OU/m^3 = (\log_{10}(\text{population}) - 4.5)/-0.6$$

(Derived from Carson and Round)

7 When assessing a new proposal, use the odour performance criterion that reflects current population density. However, when adjacent land is likely to be re-zoned in the future, a new proposal should be also assessed against the most stringent odour performance criterion of 2 OU/m^3. This should be carried out to inform local government of any potential land use conflicts that may arise in the future and to help the council plan for compatible land uses.

8 Compliance with the odour performance criteria is to be determined using source emission measurements and dispersion modelling only.

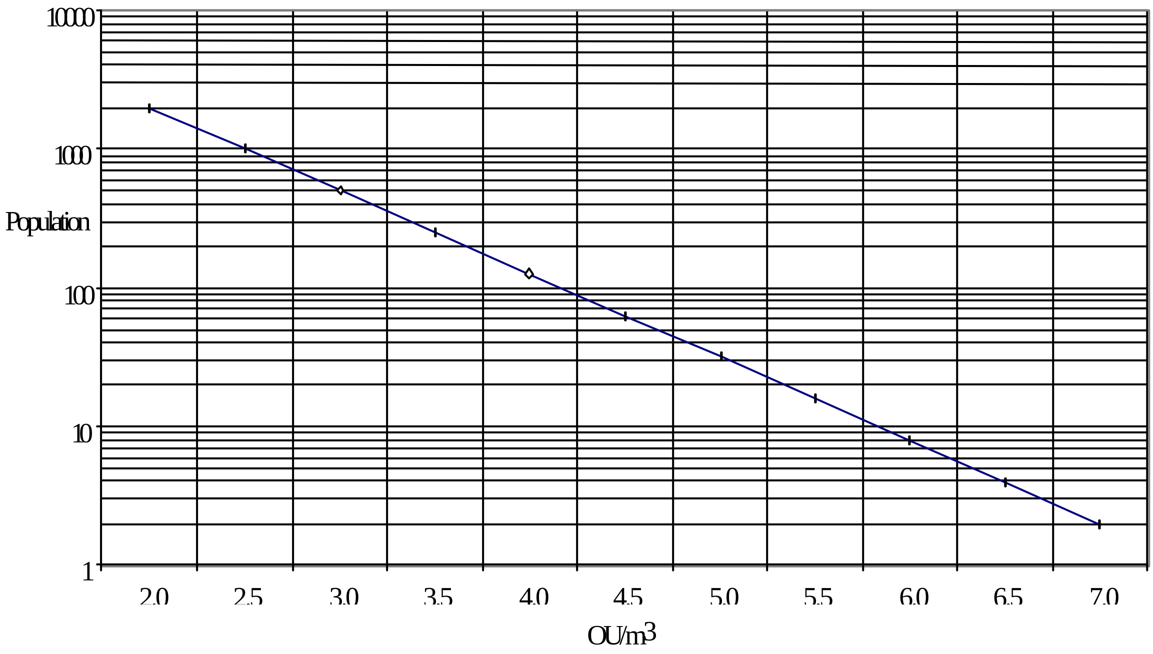
9 For point sources, the results of the dispersion modelling may be used to develop licence limit concentrations for odours from stack discharges. For diffuse sources this approach is not practical.

10 It is not appropriate to use the odour performance criteria as default licence conditions for a facility.

22 Australian Bureau of Statistics, 1996, *Household and Family Projections, Australia 1996 to 2021*, ABS Catalogue No. 3236.0

23 Australian Bureau of Statistics, 1996, *1996 Census of Population and Housing, New South Wales*

Figure 3.1 Odour performance criteria as a function of population density (derived from Carson and Round)



3.3 Developing alternative odour performance criteria

The following procedure (also set out in Figure 3.2) should be used for developing or modifying odour performance criteria for complex odours. (Note: before undertaking development of alternative criteria, the EPA should be contacted to ensure the proposed work will comply with this policy.)

1 Identify the industry type requiring a variation to the generic odour performance criteria detailed in Section 3.2.

2 Conduct odour sampling and dynamic olfactometry for all sources of odour on the site, using the procedures set out in chapter 8 of this document.

3 Install and operate a meteorological station in accordance with the procedures outlined in chapter 9 of this document.

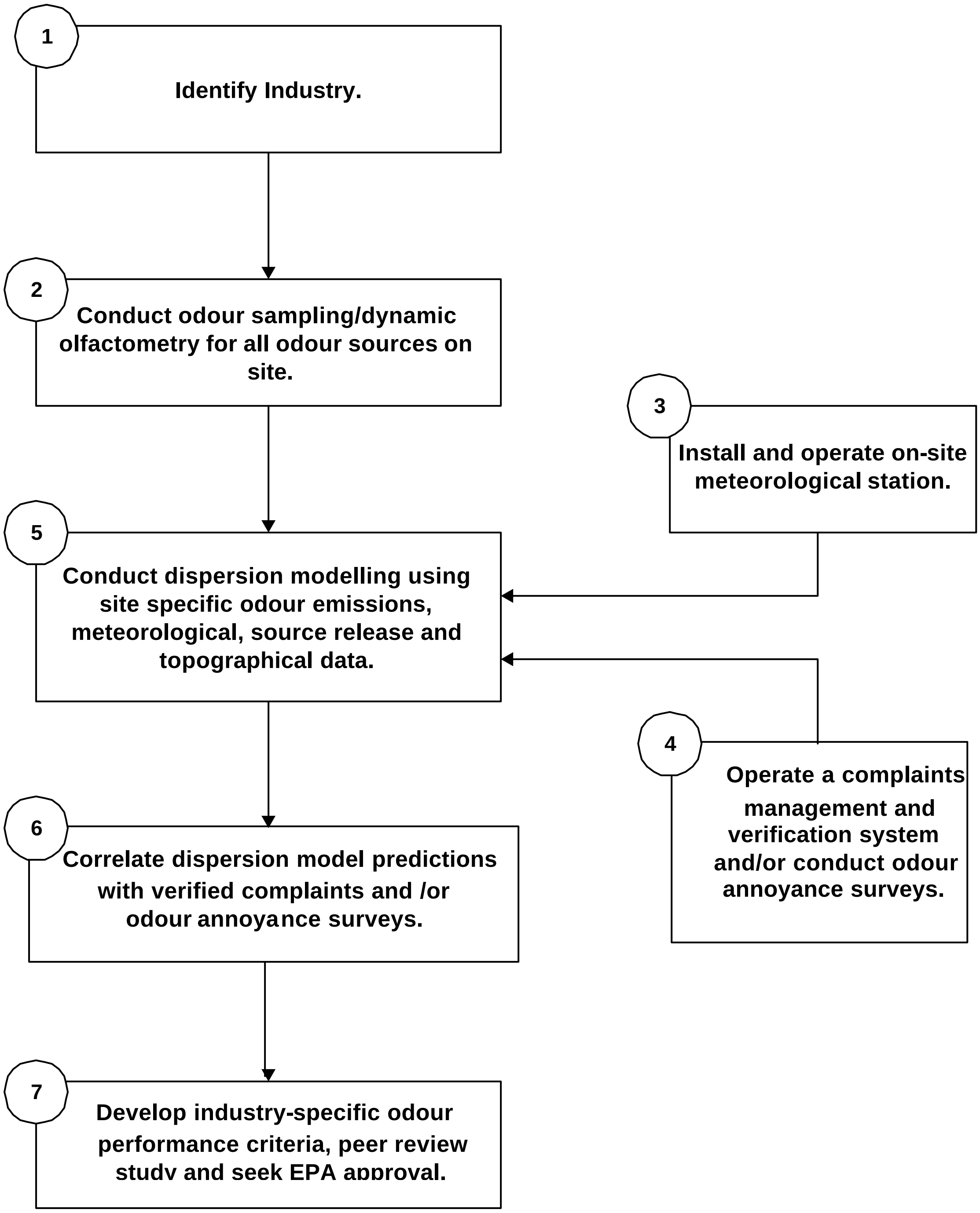
4 Design and implement a complaints management and verification system and/or carry out odour annoyance surveys.

5 Carry out a Level 3 odour impact assessment using site-specific odour emission rates, meteorological data, source release parameters, building-wake effect and topographical data and take into account any other site-specific peculiarities that may effect plume dispersion in accordance with the procedures outlined in chapter 10 of this document.

6 Correlate dispersion model predictions for a minimum period of one year with verified complaints and/or odour annoyance survey data for the same period.

7 Determine the predicted ground-level concentration of odour that corresponds with no complaints and/or annoyance, peer review the study and formally seek EPA approval to incorporate alternative odour performance criteria for the specific industry into this policy.

Figure 3.2 Procedure for determining alternative odour performance criteria



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4 Point sources: Level 1 odour impact assessment

4.1 Introduction

The Level 1 odour impact assessment process is based on simple calculations. The assessment determines whether the proposed management practices and odour emission control equipment, in combination with the distance to the nearest sensitive receptor (and likely future sensitive receptors), the topography and meteorology of the site, will result in offensive odour impacts.

The Level 1 procedure specifically takes into account the following factors:

- type of odour (e.g. complex mixture or individual odorous pollutants)
- quantity of odour emissions
- proposed management practices
- proposed level of emission control
- local topography (which may effect plume dispersion)
- the presence of buildings (which may effect plume dispersion)
- worst case meteorology
- possibility of cumulative impacts (e.g. the presence of existing activities within an existing complex or at a nearby complex with a similar odour character).

The assessment is carried out to estimate potential compliance with the glc and/or odour performance criteria (to minimise the likelihood of complaints).

This simple technique can be used to estimate the maximum allowable emission concentrations from existing stacks to ensure that offensive odours are not likely to occur. The affected zone can also be estimated.

Where new equipment is to be installed at a premises that already contains sources of similar air pollutants, the existing air quality should also be assessed. As maximum pollutant ground-level concentrations are additive, the sum total of all maximum ground-level concentrations should not exceed the glc and/or odour performance criteria.

In situations where two or more stacks are to be located in close proximity, such that their separation is less than twice the uncorrected stack height, they may be regarded as a single source with mass emission rates equal to the sum of the individual sources.

The simple formulae, which follow, can be used as an initial 'screening' assessment for estimating odour impacts. This is an approximate method only. The required level of pollution control, stack height and licence limit conditions for glc pollutants and odours should be determined using either Level 2 or Level 3 dispersion modelling.

The procedures outlined contain estimates based on research but they need to be applied with care.

4.2 Overview of the Level 1 odour impact assessment procedure

1 Estimating the required stack height

Aims

For all **new and existing** point sources:

- determine whether management practices, emission control equipment and stack height are adequate
- estimate whether the glc and odour performance criteria are likely to be met.

Steps (detailed in section 4.3)

1a Calculate the uncorrected stack height in **flat terrain**

- use Equation 4.1 for complex mixtures of odours
- use Equation 4.2 for glc pollutants.

1b Adjust the stack height determined in step 1a for **hilly terrain**

- Use Equation 4.3 for either complex mixtures of odours or glc pollutants.

1c Adjust the stack height determined in step 1b for **building-wake effects**

- Use Equations 4.4a or 4.4b for either complex mixtures of odours or glc pollutants.

2 Estimating the maximum recommended emission rate

Aims

For all **new and existing** point sources:

- determine whether management practices, emission control equipment and stack height are adequate
- determine if an existing stack will be adequate for dispersing odours from a new source
- estimate whether the glc and odour performance criteria are likely to be met.

Steps (detailed in section 4.4)

Calculate the maximum recommended emission rate

- Use Equations 4.5a or 4.5b for complex mixtures of odours
- Use Equations 4.6a or 4.6b for glc pollutants.

3 Estimating the maximum impingement concentrations on a building (e.g. air conditioning intakes)

Aims

For all **new and existing** point sources:

- determine whether management practices, emission control equipment and stack height are adequate

- estimate whether the glc and odour performance criteria are likely to be met at elevated locations on a building (e.g. air conditioning intakes) or terrain feature, where there is a sensitive receptor (or likely future sensitive receptor).

Steps (detailed in section 4.5)

Calculate the maximum impingement concentration

- use Equation 4.7 for complex mixtures of odours
- use Equation 4.8 for glc pollutants.

4 Estimating the affected zone

Aims

For all **new and existing** point sources:

- determine whether management practices, emission control equipment and stack height are adequate
- estimate whether the glc and odour performance criteria are likely to be met within the existing separation distance to the nearest sensitive receptor (or likely future sensitive receptor).

Steps (detailed in section 4.6)

Calculate the affected zone

- Use Equation 4.9 for complex mixtures of odours
- Use Equation 4.10 for glc pollutants.

4.3 Estimating the required stack height

1a Calculate the uncorrected stack height in flat terrain

Make a first estimate of the uncorrected stack height h_u for an isolated stack in flat terrain.

Equation 4.1, for complex mixtures of odours

$h_u = (0.5 \times D \times Q / opc)^{0.5}$

h_u the uncorrected stack height in m
D odour emission concentration in OU/ m^3
Q volumetric flow rate in m^3/s at 0 °C and 101.3 kPa
opc odour performance criterion in OU/ m^3, determined from Table 3.4. or Equation 3.1.

Equation 4.2, for glc pollutants

$h_u = (0.1 \times M_o / glc)^{0.5}$

h_u the uncorrected stack height in m
M_o mass emission rate of the glc pollutant in g/s
glc ground-level concentration criterion in g/ m^3, selected from Table 2.1.

In the unusual case where the stack has no buildings around it and is surrounded by flat terrain, h_u is the final height of the stack. If the stack is in flat terrain and there are buildings present, go to step 1c.

1b Adjust the stack height (determined in step 1a) for hilly terrain

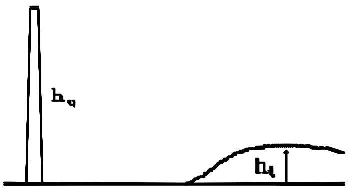
Any change in the terrain surrounding the stack, or any nearby building within a radius of ten isolated stack heights, means careful evaluation is needed. The presence of large obstacles such as hills near a stack will normally reduce the effective height of that stack. When compared to the isolated stack, maximum pollutant ground-level concentrations are higher and occur at distances nearer to the source.

This terrain correction procedure is not applicable to complex situations. In such situations, either Level 2 or Level 3 dispersion modelling will be required.

The simple terrain correction is undertaken by adding to the isolated stack h_u plus half the maximum increase in the height of hills or rising terrain h_t within a radius of ten stack heights from the location of the stack. This is called the terrain-corrected stack height h_{tc}.

Equation 4.3

$$h_{tc} = h_u + \frac{1}{2} \times h_t$$



h_{tc} terrain corrected stack height in m

h_u uncorrected stack height in m

h_t terrain height within a radius of ten stack heights in m.

If there are no buildings present, this is the final height of the stack.

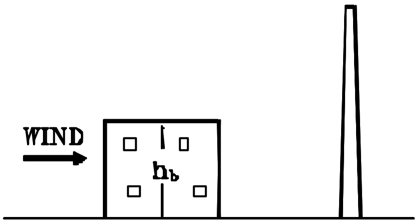
1c Adjust the stack height (determined in step 1b) for building-wake effects

The presence of large obstacles such as buildings near a stack will normally reduce the effective height of that stack. When compared to the isolated stack, maximum pollutant ground-level concentrations are higher and occur at distances nearer to the source. The greatest effect occurs when the stack is attached to a building. The aerodynamic influence becomes less significant the further away the building is from the stack. For equivalent distances, a building causes greater downwash when it is upwind of the stack. In addition, the taller the stack in relation to the nearby building, the less significant the building effect. If the ratio of the stack height to the building height is greater than 2.5 to 1 the building effect is negligible. The building wake effect formulae provided represents the worst-case situation, where the stack is attached to a building. Therefore, the application of the formula to all cases will yield conservative results.

If the stack has a nearby building, the final height of the stack required to eliminate the aerodynamic effects of the building may be estimated from the following equation.

Equation 4.4a, for situations included in Table 4.1

$h_{bw} = (A \times h_{tc}) + (B \times h_b)$



h_{bw} stack height corrected for building-wake effect in m

h_{tc} terrain-corrected stack height in m.
When there are no terrain effects $h_{tc} = h_u$

h_b height of building to the roof ridge in m

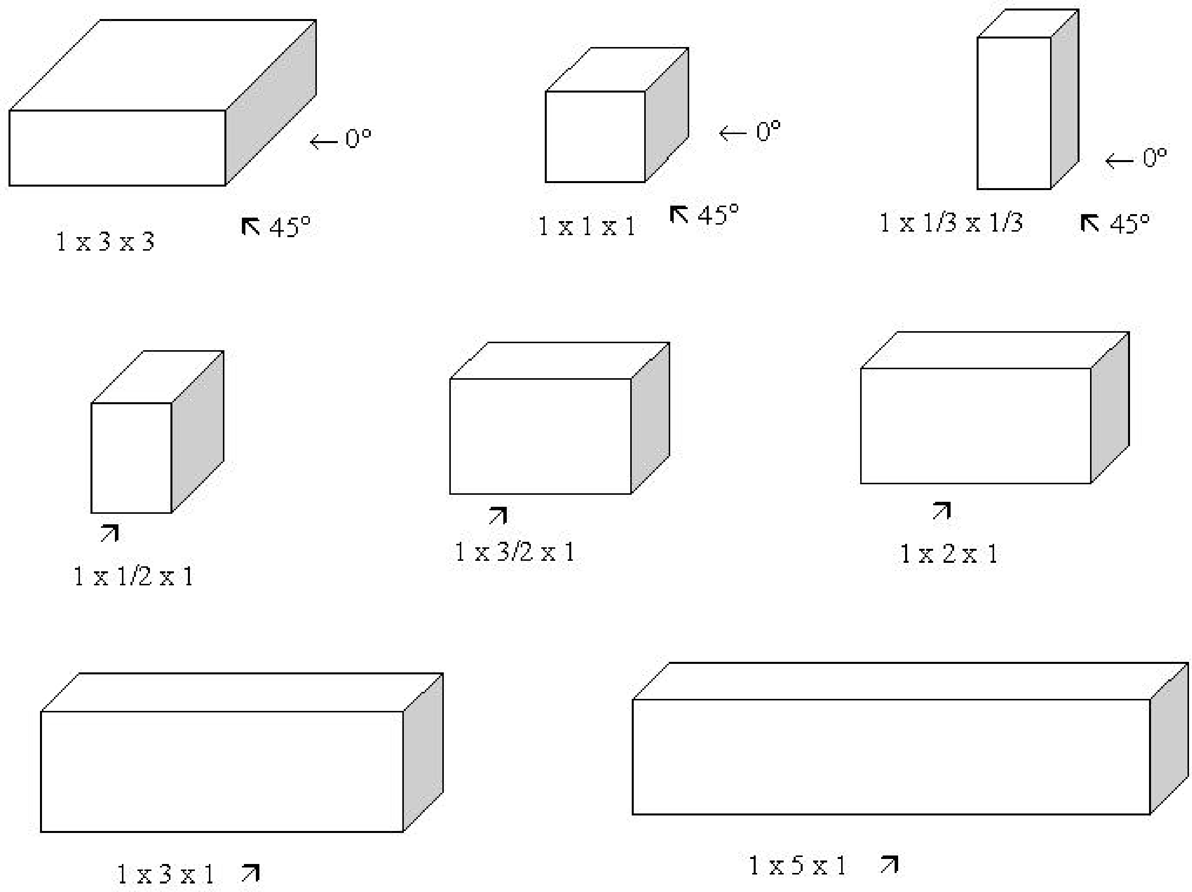
A and B are selected from Table 4.1. and Figure 4.1, below.

Table 4.1 Effective height coefficients

Building plan dimensions relative to h_b			Angle	A	B
W	L	h_b			
3	3	1	45	0.84	1.04
3	3	1	0	0.74	1.01
1	1	1	45	0.74	1.01
1	1	1	0	0.76	0.76
1/3	1/3	1	45	0.74	0.70
1/3	1/3	1	0	0.78	0.56
0.5	1	1	0	0.84	0.42
1.5	1	1	0	0.76	0.83
2	1	1	0	0.76	0.91
3	1	1	0	0.76	0.94
5	1	1	0	0.76	0.97
8	1	1	0	0.76	0.97
14	1	1	0	0.76	0.97

The building plan dimensions referred to above are the width-to-length (W:L) ratios relative to the building height (h_b). In all cases, the relative building height (h_b) has a value of 1. For a cluster of buildings, the dimensions of the envelope of that cluster should be used. The angle refers to the angle (in plan view) between the wind direction and the longitudinal axis of the building. That is, an angle of 0° denotes a wind direction normal to the building width (W) dimension. In most cases 0° should be used and 45° used when sensitive areas lie on the diagonal of the building.

Figure 4.1 Building shapes (height x width x length)



Equation 4.4b, for situations *not* included in Table 4.1

$h_{bw} = (0.56 \times C) + (0.375 \times h_b) + (0.625 \times h_{tc})$

h_{bw} stack height corrected for building-wake effect in m

C lesser of h_b and L in m

h_b height of building to the roof ridge in m

h_{tc} terrain-corrected stack height in m. When there are no terrain effects $h_{tc} = h_u$

L larger of the building width and length in m.

4.4 Estimating the maximum recommended emission rate

The following equations can be used to calculate the maximum emission rate to determine whether compliance with either the glc or the odour performance criteria is likely.

Equation 4.5a, for complex mixtures of odours and situations included in Table 4.1

$E_{OU} = opc \times ((h_{bw} - B \times h_b)/ A - ½ \times h_t)^2 / 0.5$

Equation 4.5b, for complex mixtures of odours and situations *not* included in Table 4.1

E_{OU} = opc x $((h_{bw} – 0.56 \times C – 0.375 \times h_b)/ 0.625 - ½ \times h_t)^2 / 0.5$

Equation 4.6a for glc pollutants and situations included in Table 4.1

M_o = glc x $((h_{bw} – B \times h_b)/ A - ½ \times h_t)^2 / 0.1$

Equation 4.6b for glc pollutants and situations *not* included in Table 4.1

M_o = glc x $((h_{bw} – 0.56 \times C – 0.375 \times h_b)/ 0.625 - ½ \times h_t)^2 / 0.1$

E_{OU} odour emission rate in OU/s
h_{bw} stack height corrected for building-wake effect in m
h_b height of building to the roof ridge in m
h_t terrain height within a radius of ten stack heights in m
C lesser of h_b and L in m
opc odour performance criterion in OU/ m^3, determined from Table 3.4. or Equation 3.1
M_o mass emission rate of the odorous gas in g/s
glc ground-level concentration criterion in g/ m^3, selected from Table 2.1
A and B are selected from Table 4.1.

4.5 Estimating the maximum impingement concentrations on a building

Impingement may occur and produce high concentrations on the face of a building or on hills at a considerable distance downwind of the stack, especially under stable conditions.

A plume may impinge on a building downwind of a stack. If the following formula yields a value of greater than 1, then offensive odour problems may occur at the point of impingement.

Equation 4.7, for complex mixtures of odours

$K = (35 \times E_{OU} / (opc \times X^2))$

Equation 4.8, for glc pollutants

$K = (7 \times M_o / (glc \times X^2))$

K impingement criterion (ie. greater than 1 indicates that offensive odour impacts are likely)
E_{OU} odour emission rate in OU/s. E_{OU} will need to be calculated using Equations 4.5a or 4.5b
X distance from the stack in m
opc odour performance criterion in OU/ m^3, determined from Table 3.4. or Equation 3.1
M_o mass emission rate of the odorous gas in g/s. M_o will need to be calculated using equations 4.6a or 4.6b
glc ground-level concentration criterion in g/ m^3, selected from Table 2.1.

The impingement formula contains the emission rate and separation distance alone and is independent of the height of the building. The assumption is that the centre of the plume impinges on the building. Again, this is the worst-case situation, yielding the most conservative result.

4.6 Estimating the affected zone

The maximum distance from a source at which either the glc or odour performance criteria will not be met can be estimated from the following formula.

Equation 4.9, for complex mixtures of odours

$d = (11.0 \times E_{OU} / opc)^{0.6}$

Equation 4.10 for glc pollutants

$d = (2.2 \times M_o / glc)^{0.6}$

d	radius of the affected zone in m
E_{OU}	odour emission rate in OU/s. E_{OU} will need to be calculated using equations 4.5a or 4.5b
opc	odour performance criterion in OU/ m^3, determined from Table 3.4. or Equation 3.1
M_o	mass emission rate of the odorous gas in g/s. M_o will need to be calculated using equations 4.6a or 4.6b
glc	ground-level concentration criterion in g/ m^3, selected from Table 2.1.

4.7 Worked examples

Example 1

The following worked example is presented for a hypothetical food-processing plant using the emissions data shown in Table 4.2. The plant is located in an urban area. From Table 3.4, the appropriate odour performance criterion is 2 OU/m^3.

Table 4.2 Emissions data for Example 1

Odour concentration (OU/m^3)	2000	D
Stack diameter (m)	0.4	–
Stack velocity (m/s)	2	–
Volumetric flow rate (m^3/s)	0.25	Q
Odour emission rate (OU/s)	503	E_{OU}
Building length (m)	30	–
Building width (m)	15	–
Building height (m)	15	h_b

In the following example, steps 1a, 1b, 1c, 3 and 4 are based on the data shown in Table 4.2 for a proposed development. Step 2 is based on an existing premises.

1a Estimate the uncorrected stack height in flat terrain using Equation 4.1

$h_u = (0.5 \times D \times Q / opc)^{0.5}$

$h_u = (0.5 \times 2000 \times 0.25 / 2)^{0.5}$

$h_u = 11.2$ m

1b Adjust the stack height determined in step 1a for hilly terrain, using Equation 4.3

$h_{tc} = h_u + ½ \times h_t$

The terrain is flat so no adjustment is required.

h_{tc} = 11.2 + ½ x 0

h_{tc} = 11.2 m

1c Adjust the stack height determined in step 1b for building-wake effects, using Equation 4.4a

h_{bw} = (A x h_{tc}) + (B x h_b)

The building has a length-to-width ratio relative to h_b of 2:1 (30 m/15 m:15 m/15m). For this example, the most appropriate values of A and B from Table 4.2 are 0.76 and 0.91, respectively.

h_{bw} = (0.76 x 11) + (0.91 x 15)

h_{bw} = 8.5 + 13.7

h_{bw} = 22.2 m

The stack should extend 7.2 m beyond the height of the building.

2 Estimate the maximum desirable odour emission rate, using Equation 4.5a

Assume an existing food manufacturing plant has a stack 10 m tall that is not influenced by terrain or building-wake effects and the plant is located in an urban area.

E_{OU} = opc x ((h_{bw} – B x h_b) / A – ½ x $h_t)^2$ / 0.5

Since there are no terrain or building-wake effects, h_b = 0, h_t = 0, h_{bw} = h_u and A = 1.

E_{OU} = opc x ((h_u – B x 0) / A – 1/2x0$)^2$ / 0.5

E_{OU} = opc x h^2 / 0.5

E_{OU} = 2 x $(10)^2$ / 0.5

E_{OU} = 400 OU/s

The maximum odour emission rate for this stack should be approximately 400 OU/s.

3 Estimate the maximum impingement concentrations of odour on nearby buildings, using Equation 4.7

K = (35 x E_{OU}/(opc x X^2))

The nearest air conditioning intakes are located on a building approximately 100 m from the stack.

K = (35 x 503/ (2 x 100^2))

K = 0.88.

Since K is less than 1, offensive odours should not occur.

4 Estimate the zone affected by offensive odour, using Equation 4.9

d = (11.0 x E_{OU} / opc$)^{0.6}$

d = (11.0 x 503 / 2$)^{0.6}$

d = 116 m

These simple calculations indicate that a stack height of at least 22 m would be a reasonable starting point for further design considerations. The affected zone would be approximately 116 m. Therefore, to ensure offensive odour impacts are minimised, there should be no sensitive receptors (or likely future sensitive receptors) located within 116 m.

Example 2

A proponent wishes to build a pipe-coating facility and will need to design the fume-extraction system to extract paint vapours. The major constituent present in the vapours that is likely to cause an odour problem is toluene. The plant is located in relatively flat terrain but will be subject to building-wake effects. All data is included in Table 4.3.

Table 4.3 Emissions data for Example 2

Emission rate (g/s)	10.5	M_o
Stack diameter (m)	1.6	–
Stack temperature (°K)	298	–
Stack velocity (m/s)	15	–
Building length (m)	50	–
Building width (m)	10	–
Building height (m)	10	h_b
glc (g/m^3)	$6.5x10^{-4}$	glc

In the following example, steps 1a, 1b, 1c, 3 and 4 are based on the data shown in Table 4.3 for a proposed development. Step 2 is based on an existing premises.

1a Estimate the uncorrected stack height in flat terrain, using Equation 4.2

$h_u = (0.1 \text{ x } M_o / \text{glc})^{0.5}$

$h_u = (0.1 \text{ x } 10.5 / 6.50 \text{ x } 10^{-4})^{0.5}$

$h_u = 40.19$ m

1b Adjust the stack height determined in step 1a for hilly terrain, using Equation 4.3

$h_{tc} = h_u + ½ \text{ x } h_t$

The terrain is flat so no adjustment is required.

$h_{tc} = 40.19 + ½ \text{ x } 0$

$h_{tc} = 40.19$ m

1c Adjust the stack height determined in step 1b for building-wake effects, using Equation 4.4a

$h_{bw} = (A \text{ x } h_{tc}) + (B \text{ x } h_b)$

The building has a length-to-width ratio relative to h_b of 5:1 (50 m/10 m:10 m/10m). For this example, the most appropriate values of A and B from Table 4.2 are 0.76 and 0.97, respectively.

$h_{bw} = (0.76x40.19)+(0.97x10)$

$h_{bw} = 30.54 + 9.7$

$h_{bw} = 40.24$ m.

2 Estimate the maximum desirable toluene emission rate, using Equation 4.6a

Assume an existing plant has a stack 50 m tall that is not influenced by terrain or building-wake effects.

$M_o = \text{glc x } ((h_{bw} – B \text{ x } h_b) / A – 1/2xh_t)^2 / 0.1$

Since there are no terrain or building-wake effects $h_b = 0$, $h_t = 0$, $h_{bw} = h_u$ and $A = 1$.

$M_o = \text{glc x } h^2 / 0.1$

$M_o = 6.5x10^{-4} \times (50)^2 / 0.1$

$M_o = 16.25$ g/s

The maximum toluene emission rate should be approximately 16.25 g/s.

3 Estimate the maximum impingement concentrations of toluene on nearby buildings, using Equation 4.8

$K = (7 \times M_o / (glc \times X^2))$

The nearest air conditioning intakes are located on a building approximately 400 m from the stack.

$K = (7x16{,}154/400^2)$

$K = 0.71$

Since K is less than 1, offensive odours due to toluene should not occur.

4 Estimate the zone affected by offensive odour, using Equation 4.10

$d = (2.2 \times M_o / glc)^{0.6}$

$d = (2.2x16{,}154)^{0.6}$

$d = 537$ m

These simple calculations indicate that a stack height of at least 40 m would be a reasonable starting point for further design considerations. The affected zone would be approximately 550 m. Therefore, to ensure offensive odour impacts are minimised, there should be no sensitive receptors (or likely future sensitive receptors) located within 550 m.

4.8 References

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5 Broiler chicken farms: Level 1 odour impact assessment

5.1 Introduction

This chapter sets out how to calculate separation distances for proposed broiler chicken farms that would use current standard production technology. The prescribed distances have been found to lead to an acceptable air quality impact on the amenity of the local environment.

The composite site factors and the resultant separation distances are applicable for a range of situations that would include most existing broiler chicken farms and management practices. The separation distances calculated here could be adjusted if new technology is used and it can be demonstrated and quantified that the technology will reduce odour.

This methodology allows broiler chicken shed numbers to be varied according to the management standards proposed and achieved. The distance between the broiler chicken sheds and impact areas is not increased proportionally to the number of broiler chicken sheds but is more in accordance with the probable pattern of odour dispersion. This means that large broiler chicken farms are not sited unnecessarily long distances away from impact areas.

Adopting this separation distance and broiler chicken shed numbers system will help to minimise the air quality impact associated with broiler chicken farms. This method will also assist planning authorities to provide tangible benefits to operators with proven satisfactory performance, allowing them to increase shed numbers, or conversely downgrade the classification of a broiler chicken farm and reduce shed numbers if operating standards decline.

Objectives of the impact assessment

The impact assessment aims to ensure that offensive odours do not cause unreasonable interference to the community.

Acceptable impact standard

A broiler chicken farm should not have an unreasonable impact on the amenity of the local environment and should comply with the provisions for offensive odours contained in section 129 of the POEO Act.

Approved operating practices

The most effective way of reducing offensive odour impacts is by implementing good design, good management practices and appropriate separation distances.

Environmental pollution, such as offensive odours, can be controlled by good broiler chicken shed design, good management practices, restricting broiler chicken shed numbers and maintaining suitable separation distances between broiler chicken sheds and impact areas.

All activities that are likely to increase emissions of odours, such as manure cleaning and manure spreading, should be performed at a time of day and in weather conditions, which cause least odour emission and impact on neighbouring properties.

Separation distances

There are two different ways of specifying separation distances. Both apply to proposed broiler chicken farms. Both are measured from the closest point of the broiler chicken farm to the closest point of a receptor or specified feature.

- **Fixed separation distances** specify minimum allowable distances between a broiler chicken farm and specified features such as roads, residences or watercourses. The number of broiler chicken sheds has no bearing on fixed separation distances.
- **Variable separation distances** are based on the dispersion of odours from their source. They are used to determine the allowable numbers of broiler chicken sheds and the management practices necessary to satisfy air quality objectives. A weighting factor allows for different types of premises.

5.2 Fixed separation distances

Fixed separation distances are measured as the smallest horizontal distance between the boundary of the broiler chicken farm and the specified features, as shown in Table 5.1.

Table 5.1 Fixed separation distances

Feature	Separation distance (m)
Public road – except roads described below	200
Public road – unsealed, with less than 50 vehicles per day excluding broiler chicken farm traffic	50
Major watercourse	200
Other watercourse as defined by a blue line on a current 1:50,000 NSW Government topographical map	100
Major water reservoir	800
Dairy	100
Slaughter house	100
Neighbouring rural residence	200*
Property boundary	20

* This is a minimum fixed separation distance. The variable separation distance must also be calculated and the greater of the two should be used as the separation distance.

5.3 Variable separation distances

Calculating the number of broiler chicken sheds or the size of the separation distance

The following equations assume that broiler chicken sheds are all approximately 100 m by 13 m in size and contain 22,000 chickens.

The equations provide estimates of the allowable broiler chicken shed numbers N at any one time, for a site at distance D metres from a receptor, or the distance required for a specified number of broiler chicken sheds.

Equation 5.1 is for calculating broiler chicken shed numbers for a given separation distance. Conversely, Equation 5.2 is for calculating separation distance for a given number of broiler chicken shed numbers.

Equation 5.1, Allowable broiler chicken shed numbers, given the distance

$N = (D \div S)^{1.4}$

Equation 5.2, Separation distance, given the number of broiler chicken sheds

$D = (N)^{0.71} \times S$

N number of broiler chicken sheds (assuming sheds are 100 m x 13 m and contain 22,000 chickens) or number of broiler chickens/22,000

D Separation distance in metres between the closest points of the broiler chicken sheds and the most sensitive receptor or impact location

S Composite site factor = S1 x S2 x S3 x S4 x S5. Site factors S1, S2, S3, S4 S5 relate to shed design, receptor, terrain, vegetation and wind frequency. See Tables 5.2 to 5.6.

5.4 Composite site factor

The value of S to apply in Equations 5.1 or 5.2 depends on site-specific information pertaining to the proposed shed type, receptor, terrain, vegetation and wind frequency, as set out in the following tables.

Shed factor, S1

The shed factor S1 depends on how the shed is ventilated and is determined from Table 5.2. If some sheds will have controlled ventilation and some have natural ventilation, S1 is proportional to the numbers of each type of shed.

Table 5.2 Shed factor, S1

Shed type	Value
Controlled ventilation	980
Natural ventilation	690

Receptor factor, S2

The receptor factor S2 varies depending on the likely impact area and is determined from Table 5.3.

Impact location may be a neighbour’s house, small town or large town that may be affected by odour generated at the broiler chicken sheds. Any likely future receptor locations should also be considered.

For a town, the distance is measured from the closest point of the proclaimed town boundary. For a rural farm residence, the distance is the closest part of the residence itself, excluding any yards.

Table 5.3 Receptor factor, S2

Receptor type	Value
Large towns, greater than 2000 persons	1.05
Medium towns, 500–2000 persons	0.75
Medium towns, 125–500 persons	0.55
Small towns, 30–125 persons	0.45
Small towns, 10–30 persons	0.35
Rural residence	0.30
Public area (occasional use)	0.05*

* The value for a public area would apply to areas subject to occasional use. Higher values may be appropriate for public areas used frequently or sensitive in nature, such as frequently-used halls and recreation areas. These should be assessed individually.

Terrain factor, S3

The terrain factor S3 varies according to topography and its ability to disperse odours and is determined from Table 5.4.

High relief is regarded as up-slope terrain or a hill that projects above the 10% rising slope from the broiler chicken sheds. Thus the receptor location will be either uphill from the broiler chicken sheds, behind a significant obstruction or have significant hills and valleys between the sheds and the receptor.

Low relief is regarded as terrain, which is generally below the 2% falling slope from the broiler chicken sheds. Thus the receptor will be downhill from the broiler chicken sheds.

A **valley drainage zone** has topography at low relief (as above) with significant confining sidewalls.

Topographical features at the selected site may adversely affect the odour impact under certain circumstances. During the early evening or night time, under low wind speed conditions, population centres located in a valley at a lower elevation than a broiler chicken farm may be subject to higher odour concentrations as a result of down-valley wind or the occurrence of low-level inversions. Unless site-specific information has been gathered under conditions dominated by low wind speeds, the value for the factor S3 given in Table 5.4 should apply.

Table 5.4 Terrain factor, S3

Terrain	Value
Valley drainage zone	2.0
Low relief (greater than 2% downslope from site)	1.2
Flat (less than 10% upslope, 2% downslope and not in valley drainage zone)	1.0
Undulating country between broiler chicken farm and receptor	0.9
High relief (greater than 10% upslope from site) or significant hills and valleys between broiler chicken farm and receptor	0.7

Vegetation factor, S4

The vegetation factor S4 varies according to vegetation density and is determined from Table 5.5. The vegetation density is assessed by the effectiveness with which the vegetation stand will reduce odour by dispersion.

The tree cover may disappear during the life of the broiler chicken sheds, requiring a change in broiler chicken shed numbers at that time.

The values suggested for S4 given in Table 5.5 should be used with care by regulatory bodies and a number of provisions should qualify an approval given on this basis. For example, no concession should be given for an *intention* to plant a barrier and should an occupier fail to maintain a stipulated barrier then a reduction in the allowed number of broiler chicken sheds would be necessary.

Operators should be encouraged to plant and maintain upper-storey and lower-storey vegetation, which would not cast shadows on to the broiler chicken sheds. This will improve visual amenity and odour dispersion.

Table 5.5 Vegetation factor, S4

Vegetation	Value
Crops only, no tree cover	1.0
Few trees, long grass	0.9
Wooded country	0.7
Heavy timber	0.6
Heavy forest (both upper and lower storey)	0.5

Wind frequency factor, S5

The wind frequency factor S5 is determined from Table 5.6. The wind speed and direction varies annually and diurnally (that is by the season and by the hour of the day). Although there is generally one direction that is the most frequently observed (prevailing wind), the wind direction usually blows from all directions at some time.

The wind can be classed as **high frequency** towards the receptor if the wind is blowing towards the receptor (± 40 degrees) with a frequency of at least 60 % of the time for all hours over a whole year.

The wind can be classed as **low frequency** towards the receptor if the wind is blowing towards the receptor (± 40 degrees) with a frequency of less than 5 % of the time for all hours over a whole year.

Table 5.6 Wind frequency factor, S5

Wind frequency	Value
High frequency towards receptor (greater than 60%)	1.5
Normal wind conditions	1.0
Low frequency towards receptor (less than 5%)	0.7

Applying the equations

Manure stockpiles

When working out separation distances, manure/litter stockpile areas should be regarded as broiler chicken sheds until evidence dictates otherwise.

Large broiler chicken farms or complex sites

For larger broiler chicken farms intended to accommodate more than 250,000 birds, or broiler chicken farms located in complex topographic or meteorological features, a Level 2 or Level 3 odour impact assessment may be required to confidently establish a suitable separation distance or the most suitable number of broiler chicken sheds. For large broiler chicken farms or complex situations on-site meteorological data will be required.

5.5 Two broiler chicken farms in close proximity

The following applies to separation distances, as determined by Equation 5.2.

Where a second broiler chicken farm is proposed (whether on the same or another property) the two broiler chicken farms may need to be considered as one or separate broiler chicken farms depending on their distance from each other and their distance from the receptor in question. Further, if they are considered as separate entities, the separation distance between the second broiler chicken farm and a receptor may need to be modified.

Two broiler chicken farms considered as one

For calculating the separation distance to a receptor, the two broiler chicken farms can be considered as one single broiler chicken farm if they are closer than **half the shortest separation distance** from each broiler chicken farm to the receptor.

For example, if two broiler chicken farms have individual separation distances of 400 metres and 600 metres from a receptor, then they shall be assumed to be one broiler chicken farm for the purpose of calculating separation distances if they are closer than 200 metres from one another. If the broiler chicken farms are further apart than 200 metres, they shall be treated as separate broiler chicken farms.

Two broiler chicken farms considered separately

Where the two broiler chicken farms are considered as separate entities, a 20% increase in separation distance may apply to the proposed second broiler chicken farm. For each broiler chicken farm:

1. add 20% to the required separation distance
2. consider this distance as the radius of a ‘separation zone’
3. determine whether the two zones overlap.

If the zones overlap, the added 20% applies to the separation distance of the second broiler chicken farm. If the zones don’t overlap, the ‘normal’ separation distance applies and the separation distance of the existing broiler chicken farm is not affected for its current level of operation.

These calculations would need to be undertaken for all types of sensitive receptors (and likely future sensitive receptors) to ensure that appropriate separation distances are provided.

5.6 Example separation distance calculations

Example 1: Two standard broiler chicken sheds

Scenario

A broiler chicken farm with two standard size sheds, full natural ventilation, flat topography, no significant trees and normal wind conditions.

Site data

S1	690	(Table 5.2, Natural ventilation)
S2	0.3 for a house and 0.55 for a town > 125 people (Table 5.3)	
S3	1.0	(Table 5.4, Flat topography)
S4	1.0	(Table 5.5, No tree cover)
S5	1.0	(Table 5.6, Normal wind frequency)

Equation 5.2

$D = (N)^{0.71} \times S$

Calculation

The minimum distance from a rural residence is:

$(2)^{0.71} \times 690 \times 0.3 \times 1.0 \times 1.0 \times 1.0 = 339$ metres

The minimum distance from a town >125 people is:

$(2)^{0.71} \times 690 \times 0.55 \times 1.0 \times 1.0 \times 1.0 = 621$ metres

Example 2: Five standard broiler chicken sheds

Scenario

A broiler chicken farm with five standard size sheds, full natural ventilation, flat topography, no significant trees and normal wind conditions.

Site data

S1	690	(Table 5.2, Natural ventilation)
S2	0.3 for a house and 0.55 for a town > 125 people (Table 5.3)	
S3	1.0	(Table 5.4, Flat topography)
S4	1.0	(Table 5.5, No tree cover)
S5	1.0	(Table 5.6, Normal wind frequency)

Equation 5.2

$D = (N)^{0.71} \times S$

Calculation

The minimum distance from a rural residence is:

$(5)^{0.71} \times 690 \times 0.3 \times 1.0 \times 1.0 \times 1.0 = 649$ metres

The minimum distance from a town >125 people is:

$(5)^{0.71} \times 690 \times 0.55 \times 1.0 \times 1.0 \times 1.0 = 1190$ metres

Example 3: Five standard broiler chicken sheds

Scenario

A broiler chicken farm with five standard size sheds, full natural ventilation, significant hills between the farm and a neighbouring house, wooded country and high frequency of winds towards the house.

Site data

S1	690	(Table 5.2, Natural ventilation)
S2	0.3 for a house and 0.55 for a town > 125 people (Table 5.3)	
S3	0.7	(Table 5.4, High relief topography)
S4	0.7	(Table 5.5, Wooded country)
S5	1.5	(Table 5.6, High wind frequency towards house)

Equation 5.2

$D = (N)^{0.71} \times S$

Calculation

The minimum distance from a rural residence is:

$(5)^{0.71} \times 690 \times 0.3 \times 0.7 \times 0.7 \times 1.5 = 477$ metres

The minimum distance from a town >125 people is:

$(5)^{0.71} \times 690 \times 0.55 \times 0.7 \times 0.7 \times 1.5 = 875$ metres

5.7 References

Jiang, J. and Sands, J., 1998, *Report on Odour Emissions from Poultry Farms in Western Australia*, Odour Research Laboratory, Centre for Water and Waste Technology, School of Civil and Environmental Engineering, UNSW

Queensland Department of Primary Industries, 1989, *Guidelines for Establishment and Operation of Cattle Feedlots*

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South Australian Environment Protection Agency, 1998, *Guidelines for Establishment of Intensive Piggeries in South Australia*

6 Intensive piggeries: Level 1 odour impact assessment

6.1 Introduction

This chapter sets out how to calculate separation distances for proposed piggeries that would use current standard production technology. The prescribed distances have been found to lead to an acceptable impact on the amenity of the local environment.

The composite site factors and the resultant separation distances are applicable for a range of situations that would include most existing piggeries, effluent management systems and management practices. The separation distances calculated here could be adjusted if new technology is used and it can be demonstrated and quantified that the technology will reduce odour.

This methodology allows pig numbers to be varied according to the management standards proposed and achieved. The distance between the piggery and impact areas is not increased proportionally to the number of pigs but is more in accordance with the probable pattern of odour dispersion. This means that large piggeries are not sited unnecessarily long distances away from impact areas.

Adopting this separation distance and pig numbers system will help to minimise the air quality impact associated with piggeries. This method will also assist planning authorities to provide tangible benefits to operators with proven satisfactory performance, allowing them to increase pig numbers, or conversely downgrade the classification of a piggery and reduce pig numbers if operating standards decline.

Objectives of the impact assessment

The impact assessment aims to ensure that offensive odours do not cause unreasonable interference to the community.

Acceptable impact standard

A piggery should not have an unreasonable impact on the amenity of the local environment and should comply with the provisions for offensive odours contained in section 129 of the POEO Act.

Approved operating practices

The most effective way of reducing odour potential is by implementing good design, good management practices and appropriate separation distances.

Environmental pollution, such as offensive odours, can be controlled by good piggery design, good management practices, restricting pig numbers and maintaining suitable separation distances between piggeries and impact areas.

All activities that are likely to increase emissions of odours, such as manure spreading or effluent irrigation, should be performed at a time of day and in weather conditions, which cause least odour emission and impact on neighbouring properties.

Definition of piggery complex

A ‘piggery complex’ includes:

- all buildings where pigs are housed
- adjoining or nearby areas where pigs are yarded, tended, loaded and unloaded
- areas where animal wastes from the piggery are accumulated or treated pending removal or disposal
- facilities where pigs are fed, or areas in which the feed is stored, handled or prepared.

Separation distances

There are two different ways of specifying separation distances. Both apply to proposed piggeries. Both are measured from the closest point of the piggery complex to the closest point of a receptor or specified feature.

- **Fixed separation distances** specify minimum allowable distances between a piggery complex and specified features such as roads, residences or watercourses. The number of pigs has no bearing on fixed separation distances.
- **Variable separation distances** are based on the dispersion of odours from their source. They are used to determine the allowable numbers of pigs and the management practices necessary to satisfy air quality objectives. A weighting factor allows for different types of premises.

6.2 Fixed separation distances

Fixed separation distances are measured as the smallest horizontal distance between the boundary of the piggery complex and the specified features, as shown in Table 6.1.

Table 6.1 Fixed separation distances

Feature	Separation distance (m)
Public road – except roads described below	200
Public road – unsealed, with less than 50 vehicles per day excluding piggery traffic	50
Major watercourse	200
Other watercourse as defined by a blue line on a current 1:50,000 NSW Government topographical map	100
Major water reservoir	800
Dairy	100
Slaughter house	100
Neighbouring rural residence	200*
Property boundary	20

* This is a minimum fixed separation distance. The variable separation distance must also be calculated and the greater of the two should be used as the separation distance.

6.3 Variable separation distances

Calculating the number of pigs or the size of the separation distance

The equations provide estimates of the allowable pig numbers N at any one time for a site at distance D metres from a receptor, or the distance for a specified number of pigs.

Equation 6.1 is for calculating pig numbers for a given separation distance. Conversely, Equation 6.2 is for calculating separation distance for a given number of pigs.

Equation 6.1, Allowable pig numbers, given the distance

$$N = (D / (50 \times S))^2$$

Equation 6.2, Separation distance, given the pig numbers

$$D = \sqrt{N} \times 50 \times S$$

N Number of standard pig units (SPU). A standard pig unit is defined as a grower pig of 26–60 kilograms live weight. See Table 6.2 for converting other types and weights of pig to SPU

D Separation distance in metres between the closest points of the piggery complex and the most sensitive receptor or impact location

S Composite site factor = S1 x S2 x S3 x S4 x S5. Site factors S1, S2, S3, S4 and S5 are determined according to site-specific information relating to shed design, maintenance schedule, receptor, terrain, vegetation and wind factor. See Tables 6.3 to 6.8.

Standard pig units

Piggeries either have a range of pigs, from farrowing to finisher, or cater for only one type of pig (e.g. growers only). Larger pigs usually produce more manure and hence have a greater potential for odour production. For a piggery growing from farrowing to finishers, the number of SPU can be estimated by multiplying the total number of (dry and lactating) sows by ten. Table 6.2 can be used for more refined calculations. It allows the manure and odour potential of different weight pigs to be derived from SPU.

Table 6.2 Standard pig units conversion table

Type of pig	Approximate weight range (kg)	Number of standard pig units (SPU)
Boar	100–250	1.6
Gestating Sow/Gilt	160–250/100–160	1.8
Lactating Sows	160–250	2.5
Suckers/early weaners	1.4–8	0.1
Weaners	8–25 (16)	0.5
Grower	26–60 (40)	1.00
Finisher	61–100 (75)	1.6

Final pig numbers are calculated from Table 6.2 using the approximate live weight and type. Total standard pig numbers are calculated by multiplying the number of pigs in each class by the above conversion factors and then adding the totals.

Worked example, SPU conversion factors

For a piggery with 330 weaners, 250 growers and 250 finishers the total number of SPU is:

(330 x 0.5) + (250 x 1) + (250 x 1.6) = 815 SPU.

6.4 Composite site factor

The value of S to apply in Equations 6.1 or 6.2 depends on site-specific information pertaining to the proposed shed design, maintenance schedule, receptor, terrain, vegetation and wind frequency, as set out in the following tables.

Odour potential factor, S1

The odour potential factor S1, for each class of piggery, varies with the shed design and maintenance schedule. It can be determined from Table 6.3 by multiplying the factors together ie. A x B x C x D x E. The S1 factor can be no lower than 0.5.

The reduction factor could be adjusted if there is a new technology that can be demonstrated and quantified to reduce the odour.

Table 6.3 Odour potential factor, S1

Odour potential factors			Value
A	**Type of building**		
	1	Slatted floor and deep pit	1.0
	2	Partly slatted floor and shallow pit or open drain with regular flushing	0.9
	3	Partly slatted floor and sloping floor and regular flushing	0.8
	4	Partly slatted floor and 'pull plug' and recharge system	0.6
B	**Ventilation of buildings**		
	1	Limited ridge and side-ventilators (or side only) or limited forced (fan) ventilation	1.0
	2	Ridge ventilators which are at least 90% of the length and are at least 10% of the width wide and side ventilators are at least 90% of the length of the two long sides and at least 30% of the wall height, with roof and walls insulated	0.9
	3	Fan forced ventilated shed with well designed uniform ventilation throughout shed	0.9
C	**Effluent collection frequency within all pig buildings**		
	1	Faeces, urine and other biological material removed from the confines of the buildings every 24 hours or less often	1.0
	2	Faeces, urine and other biological material removed from the confines of the buildings while essentially aerobic but in no case less often than 24 hours	0.9
D	**Effluent treatment system (within the piggery compound)**		
	1	Anaerobic lagoon(s) (including all inlet pipes/channels)	1.0
	2	Series lagoons anaerobic/aerobic (or facultative) and evaporation lagoons	1.0
	3	Facultative lagoon(s) (including all inlet pipes/channels)	0.95
	4	Aerated lagoon(s) (aerobic surface layer over entire lagoon)	0.75
	5	Aerobic lagoon(s)	0.6
	6	No effluent storage within at least 500 m of the piggery	0.6

Odour potential factors		Value
E	Feeding	
	1 Conventional feeding	1.0
	2 Phase feeding	0.9
	3 Phase feeding with optimal protein	0.8

Note about S1 factor

- S1 = A x B x C x D x E
- Assumes a reasonably high standard at all piggeries, which is achieved by good management and control of odour generating procedures. Table 6.3 gives factors, which relate to the odour potential for different shed types and effluent management systems. Generally the factors would be 1.0 and lower. Hence if 1.0 is used the separation distances will be the maximum. Separation distances would be less for developments with lower potential odour emissions.
- The S1 factor can be no lower than 0.5
- The S1 factor could be adjusted if there is new technology, which can be demonstrated and quantified to reduce the odour.
- Where different production systems, as set out in Table 6.3, apply within the piggery complex, several S1 factors should be selected according to the SPU within each production system.

Eco-huts

The S1 factor for eco-huts stocked at recommended rates with good management practices is 0.5. Where stocked at higher rates and/or without good management the S1 factor is 0.75.

For eco-huts the odour potential depends on the stocking density. When calculating the space required consideration must always be given to the final or outgoing weight and age of the pigs. For a guide to minimum stocking densities see the following table. As new research data and further experience with eco-huts is gained then these stocking densities may be able to be adjusted.

Table 6.4 Eco-hut stocking densities

Pig age (weeks)	Pig weight (kg)	Stocking area (m^2/pig)
3	6	0.2
6	13	0.3
9	24	0.4
12	35	0.5
15	50	0.7
18	65	0.8
21	82	0.9
24	102	1.0
>52	>160	3.00

Receptor factor, S2

The receptor factor S2 varies depending on the likely impact area and is determined from Table 6.5.

Impact location may be a neighbour's house, small town or large town that may be affected by odour generated at the piggery. Any likely future receptor locations should also be considered.

For a town, the distance is measured from the closest point of the proclaimed town boundary. For a rural farm residence, the distance is the closest part of the residence itself, excluding any yards.

Table 6.5 Receptor factor, S2

Receptor type	Value
Large towns, greater than 2000 persons	1.6
Medium towns, 500–2000 persons	1.2
Medium towns, 125–500 persons	1.1
Small towns, 30–125 persons	1.0
Small towns, 10–30 persons	0.6
Rural residence	0.3
Public area (occasional use)	0.05*

* The value for a public area would apply to areas subject to occasional use. Higher values may be appropriate for public areas used frequently or sensitive in nature, such as frequently-used halls and recreation areas. These should be assessed individually.

Terrain factor, S3

The terrain factor S3 varies according to topography and its ability to disperse odours and is determined from Table 6.6.

High relief is regarded as up-slope terrain or a hill that projects above the 10% rising slope from the piggery. Thus the receptor location will be either uphill from the piggery, be behind a significant obstruction or have significant hills and valleys between the piggery and the receptor.

Low relief is regarded as terrain, which is generally below the 2% falling slope from the piggery. Thus the receptor will be downhill from the piggery.

A **valley drainage zone** has topography at low relief (as above) with significant confining sidewalls.

Topographical features of the selected site may adversely affect the odour impact under certain circumstances. During the early evening or night time under low wind speed conditions, population centres located in a valley complex at a lower elevation than a piggery may be subject to higher odour concentrations as a result of down-valley wind or the occurrence of low-level inversions. Unless site-specific information has been gathered under conditions dominated by low wind speeds, the value for the factor S3 given in Table 6.6 should apply.

Table 6.6 Terrain factor, S3

Terrain	Value
Valley drainage zone	2.0
Low relief (greater than 2% downslope from site)	1.2
Flat (less than 10% upslope, 2% downslope and not in valley drainage zone)	1.0
Undulating country between piggery and receptor	0.9
High relief (greater than 10% upslope from site) or significant hills and valleys between piggery and receptor	0.7

Vegetation factor, S4

The vegetation factor S4 varies according to vegetation density and is determined from Table 6.7. The vegetation density is assessed by the effectiveness with which the vegetation stand will reduce odour by dispersion.

The tree cover may disappear during the life of the piggery requiring a change in pig numbers at that time.

The values suggested for S4 given in Table 6.7 should be used with care by regulatory bodies and a number of provisions should qualify an approval given on this basis. For example, no concession should be given for an *intention* to plant a barrier and should an occupier fail to maintain a stipulated barrier then a reduction in the allowed number of pigs would be necessary.

Operators should be encouraged to plant and maintain upper-storey and lower-storey vegetation, which would not cast shadows on the piggery. This will improve visual amenity and odour dispersion.

Table 6.7 Vegetation factor, S4

Vegetation	Value
Crops only, no tree cover	1.0
Few trees, long grass	0.9
Wooded country	0.7
Heavy timber	0.6
Heavy forest (both upper and lower storey)	0.5

Wind frequency factor, S5

The wind frequency S5 factor is determined from Table 6.8. Wind speed and direction varies by the season and by the hour of the day. Although there is generally one direction that is the most frequently observed (prevailing wind), the wind direction usually blows from all directions at some time.

The wind can be classed as **high frequency** towards the receptor if the wind is blowing towards the receptor (± 40 degrees) with a frequency of at least 60 % of the time for all hours over a whole year.

The wind can be classed as **low frequency** towards the receptor if the wind is blowing towards the receptor (± 40 degrees) with a frequency of less than 5 % of the time for all hours over a whole year.

Table 6.8 Wind frequency factor, S5

Wind frequency	Value
High frequency towards receptor (greater than 60%)	1.5
Normal wind conditions	1.0
Low frequency towards receptor (less than 5%)	0.7

Applying the equations

Manure stockpiles

When working out separation distances, manure stockpile areas should be regarded as part of the piggery complex, until evidence dictates otherwise.

Large piggeries or complex sites

For larger piggeries that are intended to accommodate more than 2000 pigs or 200 breeding sows, or piggeries located in complex topographic or meteorological features, a Level 2 or Level 3 odour impact assessment may be required to confidently establish a suitable separation distance or the most suitable number of pigs. For large piggeries or complex situations on-site meteorological data will be required.

6.5 Two piggeries in close proximity

The following applies to separation distances, as determined by Equation 6.2.

Where a second piggery is proposed (whether on the same or another property) the two piggeries may need to be considered as one or separate piggeries, depending on their distance from each other and their distance from the receptor in question. Further, if they are considered as separate entities, the separation distance between the second piggery and a receptor may need to be modified.

Two piggeries considered as one

For calculating the separation distance to a receptor, the two piggeries can be considered as one single piggery if they are closer than **half the shortest separation distance** from each piggery to the receptor.

For example, if two piggeries have individual separation distances of 400 metres and 600 metres from a receptor, then they shall be assumed to be one piggery for the purpose of calculating separation distances if they are closer than 200 metres from one another. If the piggeries are further apart than 200 metres, they shall be treated as separate piggeries.

Two piggeries considered separately

Where the two piggeries are considered as separate entities, a 20% increase in separation distance may apply to the proposed second piggery. For each piggery:

1 add 20% to the required separation distance

2 consider this distance as the radius of a ‘separation zone’

3 determine whether the two zones overlap.

If the zones overlap, the added 20% applies to the separation distance of the second piggery. If the zones don't overlap, the 'normal' separation distance applies and the separation distance of the existing piggery is not affected for its current level of operation.

These calculations would need to be undertaken for all types of sensitive receptors (and likely future sensitive receptors) to ensure that appropriate separation distances are provided.

6.6 Example separation distance calculations

Example 1: New grow-out piggery

Scenario

A new grow-out piggery has 3000 growers and 2000 finishers. The piggery has pull-plug and recharge flushing, full ridge and side ventilation and phase feeding. The piggery is near a rural residence, on a flat site with some tree cover and normal winds.

Site data

The piggery is equivalent to 6200 standard pig units (Table 6.2)

The site factors are:

S1	0.5	(Table 6.3)
S2	0.3	(Table 6.5, Rural farm residence)
S3	1.0	(Table 6.6, Flat topography)
S4	0.9	(Table 6.7, Light tree cover)
S5	1.0	(Table 6.8, Normal wind frequency)

Equation 6.2

$D = \sqrt{N} \times 50 \times S$

Calculation

The minimum distance of the piggery from a rural residence is:

$D = \sqrt{6200} \times 50 \times 0.5 \times 0.3 \times 1.0 \times 0.9 \times 1.0$

= 531 metres.

Example 2: Farrow to finish piggery

Scenario

A farrow to finish piggery has a partly slatted and sloping floor with regular flushing and full ridge and side ventilation. It is 2500 metres from a town of between 500 and 2000 people and on flat terrain with few trees and normal wind conditions.

Site data

S1	0.72	(Table 6.3)
S2	1.2	(Table 6.5, Town of between 500 and 2000 persons)
S3	1.0	(Table 6.6, Flat topography)
S4	0.9	(Table 6.7, Few trees)
S5	1.0	(Table 6.8, Normal wind frequency)

Equation 6.1

$N = (D / (50 \times S))^2$

Calculation

The maximum number of pigs allowed is:

$N = [2500 / (50 \times 0.72 \times 1.2 \times 1.0 \times 0.9 \times 1.0)]^2$

= 4135 standard pig units or 414 sows.

6.7 Variable separation distances for waste-water treatment and waste disposal

Separation distances must be maintained between sensitive features and all effluent treatment systems and waste disposal areas. They are in addition to the separation distances for the piggery as described above and are calculated separately using Tables 6.9, 6.10 and 6.11.

The separation distances depend on the standard of treatment or method of disposal. Significant reductions in separation distance accrue from effluent treatment systems and waste disposal methods, which reduce odour production.

Distances are measured from the edge of the effluent treatment systems or the waste disposal area.

Effluent treatment systems

Normally effluent treatment systems are adjoining or close to the piggery. If this is the case, the separation distances determined from Equations 6.1 or 6.2 are adequate and special effluent-related distance requirements do not apply, except for the separation requirements for roads, water courses and property boundaries detailed in Tables 6.9 and 6.10.

Separation distances between effluent treatment systems, which are remote from the piggery itself, by at least 500 m and homes, which are not under the control of piggery management, are detailed in Table 6.9 and 6.10. The values shown apply to systems, which are correctly designed and operated. Separation distances are given for the following effluent treatment systems:

System A solids separation, anaerobic lagoon and aerobic lagoon and also straw and manure from eco-huts

System B anaerobic lagoon and aerobic lagoon

System C anaerobic lagoon only

System D drying lagoons.

Table 6.9 Separation distances surrounding effluent treatment systems, for piggeries up to 5000 standard pig units

Feature	Separation distance (m) according to effluent treatment system A	B	C	D
Large towns, greater than 2000 persons	800	1000	1500	2000
Medium towns, 500–2000 persons	600	750	1150	1500
Medium towns, 125–500 persons	550	700	1050	1400
Small towns, 30–125 persons	500	600	950	1250
Small towns, 10–30 persons	300	400	600	750
Rural residence	300	300	400	500
Public area (occasional use)	100	100	150	200
Public road – except as in Table 6.10	100	100	150	200

Piggeries greater than 5000 standard pig units

For piggeries bigger than 5000 SPU use the values in Table 6.9 but increase them by the factor $\sqrt{(N/5000)}$ where N is the number of standard pig units whose effluent is stored in the effluent treatment system.

Table 6.10 Separation distances surrounding effluent treatment systems, for all sizes of piggery

Feature	Separation distance (m) according to effluent treatment system A	B	C	D
Public road – unsealed with less than 50 vehicles per day, excluding piggery traffic	50	50	50	50
Major water reservoir	800	800	800	800
Major watercourse and flood zone	200	200	200	200
Other watercourse, as defined by a blue line on a 1:50,000 current NSW Government topographical map	100	100	100	100
Property boundary	20	20	20	20

Categories for solid and liquid waste disposal to land

Use Table 6.11 (see next page) to calculate separation distances for the following categories of waste disposal method:

Waste disposal category A

- Discharge by injection directly into the soil, at a rate not exceeding the hydraulic, nutrient or salinity limits for the local soil types
- Irrigation of liquid pig effluent, diluted at a ratio of 20:1 or greater and projected at a height of less than 2 m

Waste disposal category B

- Land receiving effluent that are ‘fresh’ (less than 12 hours old) and have solid content not greater than 5%
- Aerated effluent, from which at least 75% solids have been removed
- Any effluent with a B.O.D. value of less than 2500 mg/l
- Solids that have been completely composted
- Effluent with a solid content not greater than 1%
- Mechanical spreaders in combination with ‘ploughing-in’ type equipment

Waste disposal category C

- Downward effluent discharge nozzles
- Discharged material is not projected to a height of more than 2 m above ground level

Waste disposal category D

- All effluent discharged or projected to a height greater than 2 m above ground level
- Liquid effluent in which water remains visible on the soil surface for periods in excess of one hour
- Separated solids or sludge (except fully composted solids) that remain on the soil surface for more than 24 hours (ie. are not immediately ploughed in).

Where the disposal methods used fall into more than one of these categories, use the category that provides the greatest separation distance.

When waste is to be spread or discharged, the piggery management should take into account actual and forecast wind conditions to prevent any waste being carried by the wind, or the creation of offensive odours at neighbouring properties.

Table 6.11 Separation distances surrounding waste disposal areas

	Separation distance (m) according to waste disposal category *			
Feature	**A**	**B**	**C**	**D**
Large towns, greater than 2000 persons	500	1000	1500	2000
Medium towns, 500–2000 persons	400	750	1150	1500
Medium towns, 125–500 persons	350	700	1050	1400
Small towns, 30–125 persons	300	600	950	1250
Small towns, 10–30 persons	200	400	550	750
Rural residence **	100	200	300	400
Public area (occasional use)	50	100	150	200
Public road – except as below	25	25	50	75
Public road – unsealed with less than 50 vehicles per day excluding piggery traffic	10	10	15	15
Major water reservoir	800	800	800	800
Major watercourse and flood zone	100	200	200	200
Other watercourses as defined by a blue line on a 1:50,000 current NSW Government topographical map	50	50	50	100

* If the wind is blowing towards a receptor, the separation distance should be increased by 50%.

** The distances for neighbouring rural farm residences can, on a daily basis, be reduced by agreement.

6.8 References

South Australian Environment Protection Agency, 1997, *Draft Guidelines for the Establishment of Poultry Farms in South Australia*

South Australian Environment Protection Agency, 1998, *Guidelines for Establishment of Intensive Piggeries in South Australia*

Queensland Department of Primary Industries, 1989, *Guidelines for Establishment and Operation of Cattle Feedlots*

Queensland Department of Primary Industries, 2000, *Reference Manual for the Establishment and Operation of Cattle Feedlots in Queensland*

7 Cattle feedlots: Level 1 odour impact assessment

7.1 Introduction

This chapter sets out how to calculate separation distances for proposed cattle feedlots that would use current standard production technology. The prescribed distances have been found to lead to an acceptable impact on the amenity of the local environment.

The composite site factors and the resultant separation distances are applicable for a range of situations that would include most existing cattle feedlots, effluent management systems and management practices. The separation distances calculated here could be adjusted if new technology is used and it can be demonstrated and quantified that the technology will reduce odour.

This methodology allows cattle numbers to be varied according to the management standards proposed and achieved. The distance between the cattle feedlot and impact areas is not increased proportionally to the number of cattle but is more in accordance with the probable pattern of odour dispersion. This means that large cattle feedlots are not sited unnecessarily long distances away from impact areas.

Adopting this separation distance and cattle numbers system will help to minimise the air quality impact associated with cattle feedlots. This method will also assist planning authorities to provide tangible benefits to operators with proven satisfactory performance, allowing them to increase cattle numbers, or conversely downgrade the classification of a cattle feedlot and reduce cattle numbers if operating standards decline.

Objectives of the impact assessment

The impact assessment aims to ensure that offensive odours do not cause unreasonable interference to the community.

Acceptable impact standard

A cattle feedlot should not have an unreasonable impact on the amenity of the local environment and should comply with the provisions for offensive odours contained in section 129 of the POEO Act.

Approved operating practices

The most effective way of reducing odour potential is by implementing good design, good management practices and appropriate separation distances.

Environmental pollution, such as offensive odours, can be controlled by good cattle feedlot design, good management practices, restricting cattle numbers and maintaining suitable separation distances between cattle feedlots and impact areas.

All activities that are likely to increase emissions of odours, such as manure spreading or effluent irrigation, should be performed at a time of day and in weather conditions, which cause least odour emission and impact on neighbouring properties.

Variations in Impact

Because of differences in climatic conditions and population densities, different feedlots have a varying effect on impact areas. To accommodate these variations, these guidelines define a range of feedlot classes. Odour control requirements vary for each class, according to the feedlot's size, location, design, management and likely effects on impact areas.

For all feedlots, in any class, it is essential to prevent effluent from discharging into watercourses.

Separation distances

There are two different ways of specifying separation distances. Both apply to proposed cattle feedlots. Both are measured from the closest point of the cattle feedlot to the closest point of a receptor or specified feature.

- **Fixed separation distances** specify minimum allowable distances between a cattle feedlot and specified features such as roads, residences or watercourses. The number of cattle has no bearing on fixed separation distances.
- **Variable separation distances** are based on the dispersion of odours from their source. They are used to determine the allowable numbers of cattle and the management practices necessary to satisfy air quality objectives. A weighting factor allows for different types of premises.

7.2 Feedlot classes

Class 1

This represents the highest standard of design, operation, maintenance, pad management and cleaning frequency. Since this category has the potential to carry large numbers of cattle relatively close to impact areas, any conditions, which could lead to excessive odour production, cannot be tolerated. The EPA would be unlikely to approve a Class 1 feedlot until satisfactory performance at Class 2 status has been demonstrated.

Class 2

The generally accepted standard for a well designed, constructed and maintained feedlot, with a high standard of operation. This is the reference standard for all classes.

Class 3

Well-designed, well-constructed and operated with higher standards than Class 4 for pad preparation and maintenance and pen cleaning. Well removed from impact locations.

Class 4

Generally a small feedlot in an isolated situation with basic management and development standards, well separated from any residential situations and having fewer than 1000 head of cattle.

7.3 Fixed separation distances

Fixed separation distances are measured as the smallest horizontal distance between the boundary of the cattle feedlot and the specified features, as shown in Table 7.1.

Table 7.1 Fixed separation distances

Feature	Separation distance (m)
Public road – except roads described below	200
Public road – unsealed, with less than 50 vehicles per day excluding cattle feedlot traffic	50
Major watercourse	200
Other watercourse as defined by a blue line on a current 1:50,000 NSW Government topographical map	100
Major water reservoir	800
Dairy	100
Slaughter house	100
Neighbouring rural residence	200*
Property boundary	20

* This is a minimum fixed separation distance. The variable separation distance must also be calculated and the greater of the two should be used as the separation distance.

7.4 Variable separation distances

Calculating the number of cattle or the size of the separation distance

The equations provide estimates of the allowable cattle numbers N at any one time for a site at distance D metres from an impact distance, or the distance for a specified number of cattle.

Equation 7.1 estimates the allowable cattle numbers N for a site at distance D metres from a receptor. Conversely, Equation 7.2 gives the separation distance required for a specified number of cattle.

Equation 7.1, Allowable cattle numbers, given the distance

$N = (D \div S)^2$

Equation 7.2, Separation distance, given the number of cattle

$D = \sqrt{N} \times S$

N Number

D Separation distance in metres from pens and stockpiles

S Composite site factor = S1 x S2 x S3 x S4 x S5. Site factors S1, S2, S3, S4 and S5 are determined according to site-specific information relating to stocking density, feedlot class, receptor, terrain, vegetation and wind factor. See Tables 7.2 to 7.5.

7.5 Composite site factor

Stocking factor, S1

The stocking factor S1, for each class of feedlot, varies with the minimum stocking density proposed. Stocking factor is determined from Table 7.2a or Table 7.2b, depending on annual rainfall.

Moisture content and the rate of deposition of manure are major factors influencing odour production rate from the manure pack.

Values of S1 have been derived for selected stocking densities. Data collected in field trials and field observations was used to identify the relationship between odour production rate and the stocking density. The values were derived using field trial relationships between odour generation rates and stocking density for the various feedlot categories (defined by pad moisture content) and with model predicted odour levels at impact locations (calibrated using the observed odour impact at some existing feedlots).

Table 7.2a Stocking factor, S1, average annual rainfall *less* than 750 mm

	Stocking density (m^2/beast)		
Feedlot class	**10**	**15**	**20**
1	65	52	40
2	95	78	58
3	128	103	78
4	158	127	96

Table 7.2b Stocking factor, S1, average annual rainfall *greater* than 750 mm

	Stocking density (m^2/beast)		
Feedlot class	**15**	**20**	**25**
1	65	52	40
2	95	78	58
3	128	103	78
4	158	127	96

Note: Stocking density is the pen area available per head of stock held in the pen. The values given in Tables 7.2a and 7.2b assume a 450 kg beast at the start of feeding and a feeding period of 14 weeks. Proportionally higher or lower stocking densities apply to heavier or lighter beasts.

Receptor factor, S2

The receptor factor S2 varies depending on the likely impact area and is determined from Table 7.3. Impact location may be a neighbour's house, small town or a large town that may be affected by odour generated at the feedlot.

The separation distances to impact locations are usually the key factors, which limit the number of cattle, which could be accommodated on a particular site. Where environmental impact assessment is carried out, each of the critical separation distances may be assessed to determine if the adopted odour objective is applicable to that impact location.

Table 7.3 Receptor factor, S2

Receptor type	Value
Large towns, greater than 2000 persons	1.6
Medium towns, 500–2000 persons	1.2
Medium towns, 125–500 persons	1.1
Small towns, 30–125 persons	1.0
Small towns, 10–30 persons	0.6
Rural residence	0.3
Public area (occasional use)	0.05*

***** The value for a public area would apply to areas subject to occasional use. Higher values may be appropriate for public areas used frequently or sensitive in nature such as schools and frequently used halls and recreation areas. These should be assessed individually.

Terrain factor, S3

The terrain factor S3 varies according to topography and is determined from Table 7.4.

High relief is regarded as up-slope terrain of a hill that projects above the 10% rising grade line from the feedlot. Thus the receptor location will be either uphill from the feedlot or be behind a significant obstruction.

Low relief is regarded as terrain, which is generally below the 2% falling grade line from the feedlot. Thus the receptor will be downhill from the feedlot.

A **valley drainage zone** has topography at low relief (as above) with significant confining sidewalls.

Topographical features of the selected site may adversely affect the odour impact under certain circumstances. During the early evening or night time under low wind speed conditions, population centres located in a valley complex at a lower elevation than a feedlot may be subject to higher odour concentrations as a result of down-valley wind or the occurrence of low-level inversions. Unless site-specific information has been gathered under conditions dominated by low wind speeds, the value for the factor S3 given in Table 7.4 should apply.

Table 7.4 Terrain factor, S3

Terrain	Value
Valley drainage zone	2.0
Low relief (greater than 2% downslope from site)	1.2
Flat (less than 10% upslope, 2% downslope and not in valley drainage zone)	1.0
Undulating country between cattle feedlot and receptor	0.9
High relief (greater than 10% upslope from site) or significant hills and valleys between cattle feedlot and receptor	0.7

Vegetation factor, S4

The vegetation factor S4 varies according to vegetation density and is determined from Table 7.5. The vegetation density is assessed by the effectiveness with which the vegetation stand will reduce odour by dispersion.

The tree cover may disappear during the life of the cattle feedlot requiring a change in cattle numbers at that time.

The values suggested for S4 given in Table 7.5 should be used with care by regulatory bodies and a number of provisions should qualify an approval given on this basis. For example, no concession should be given for an *intention* to plant a barrier and should an occupier fail to maintain a stipulated barrier then a reduction in the allowed number of cattle would be necessary.

Operators should be encouraged to plant and maintain upper-storey and lower-storey vegetation, which would not cast shadows on the cattle feedlot. This will improve visual amenity and odour dispersion.

The vegetation factor S4 varies according to vegetation density and is determined from Table 7.5.

Table 7.5 Vegetation factor, S4

Vegetation	Value
Crops only, no tree cover	1.0
Few trees, long grass	0.9
Wooded country	0.7
Heavy timber	0.6
Heavy forest (both upper and lower storey)	0.5

Wind frequency factor, S5

The wind frequency S5 factor is determined from Table 7.6. Wind speed and direction varies by the season and by the hour of the day. Although there is generally one direction that is the most frequently observed (prevailing wind), the wind direction usually blows from all directions at some time.

The wind can be classed as **high frequency** towards the receptor if the wind is blowing towards the receptor (± 40 degrees) with a frequency of at least 60% of the time for all hours over a whole year.

The wind can be classed as **low frequency** towards the receptor if the wind is blowing towards the receptor (± 40 degrees) with a frequency of less than 5% of the time for all hours over a whole year.

Table 7.6 Wind frequency factor, S5

Wind frequency	Value
High frequency towards receptor (greater than 60%)	1.5
Normal wind conditions	1.0
Low frequency towards receptor (less than 5%)	0.7

Applying the equations

Manure stockpiles

When working out separation distances, manure stockpile areas should be regarded as part of the cattle feedlot, until evidence dictates otherwise.

Large cattle feedlots or complex sites

For larger cattle feedlots that are intended to accommodate more than 1000 head of cattle, or cattle feedlots located in complex topographic or meteorological features, a Level 2 or Level 3 odour impact assessment may be required to confidently establish a suitable separation distance or the most suitable number of cattle. For large cattle feedlots or complex situations on-site meteorological data will be required.

7.6 Two cattle feedlots in close proximity

The following applies to separation distances, as determined by Equation 7.2.

Where a second cattle feedlot is proposed (whether on the same or another property) the two cattle feedlots may need to be considered as one or separate cattle feedlots, depending on their distance from each other and their distance from the receptor in question. Further, if they are considered as separate entities, the separation distance between the second cattle feedlot and a receptor may need to be modified.

Two cattle feedlots considered as one

For calculating the separation distance to a receptor, the two cattle feedlots can be considered as one single cattle feedlot if they are closer than **half the shortest separation distance** from each cattle feedlot to the receptor.

For example, if two cattle feedlots have individual separation distances of 1000 metres and 2000 metres from a receptor, then they shall be assumed to be one cattle feedlot for the purpose of calculating separation distances if they are closer than 500 metres from one another. If the cattle feedlots are further apart than 500 metres, they shall be treated as separate cattle feedlots.

Two cattle feedlots considered separately

Where the two cattle feedlots are considered as separate entities, a 20% increase in separation distance may apply to the proposed second cattle feedlot. For each cattle feedlot:

1 add 20% to the required separation distance

2 consider this distance as the radius of a ‘separation zone’

3 determine whether the two zones overlap.

If the zones overlap, the added 20% applies to the separation distance of the second cattle feedlot. If the zones don’t overlap, the ‘normal’ separation distance applies and the separation distance of the existing cattle feedlot is not affected for its current level of operation.

These calculations would need to be undertaken for all types of sensitive receptors (and likely future sensitive receptors) to ensure that appropriate separation distances are provided.

7.7 Example separation distance calculations

Example 1: New cattle feedlot

Scenario

A new Class 2 cattle feedlot proposes to rear 20,000 head. The cattle feedlot is located in an area with rainfall less than 750 mm, has a stocking density of 15 m^2 per beast, near a rural residence, on a flat site with few trees and normal winds.

Site data

The site factors are:

S1	78	(Table 7.2a)
S2	0.3	(Table 7.3, Rural farm residence)
S3	1.0	(Table 7.4, Flat topography)
S4	0.9	(Table 7.5, Few trees)
S5	1.0	(Table 7.6, Normal wind frequency)

Equation 7.2

D = √ N x S

Calculation

The minimum distance of the cattle feedlot from a rural residence is:

D = √ 20000 x 78 x 0.3 x 1.0 x 0.9 x 1.0

= 2978 metres.

7.8 References

South Australian Environment Protection Agency, 1997, *Draft Guidelines for the Establishment of Poultry Farms in South Australia*

South Australian Environment Protection Agency, 1998, *Guidelines for Establishment of Intensive Piggeries in South Australia*

Queensland Department of Primary Industries, 1989, *Guidelines for Establishment and Operation of Cattle Feedlots*

Queensland Department of Primary Industries, 2000, *Reference Manual for the Establishment and Operation of Cattle Feedlots in Queensland*

8 Odour sampling and analysis

8.1 Sampling and analysis of glc pollutants from point sources

The sampling and analysis methods included *in Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales* (referenced by the Clean Air (Plant and Equipment) Regulation 1997) must be used. Where there is no approved sampling and analysis method for a particular pollutant, the licensee must submit a proposed sampling and analysis method to the EPA and seek written approval from the EPA to use this method.

Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales refers to Australian Standard or USEPA methods for:

- selecting sampling positions (TM-1)
- determining velocity and volumetric flow rate (TM-2 or CEM-6)
- determining temperature in stack gases (TM-2 or TM-15)
- determining moisture content in stack gases (TM-22)
- determining dry gas density/molecular weight of stack gases (TM-23)
- determining carbon dioxide in stack gases (TM-24 or CEM-3)
- determining oxygen in stack gases (TM-25 or CEM-3)
- determining emission concentration for a broad range of pollutants:
  - sulfuric acid mist (TM-3)
  - hydrogen sulfide (TM-5 or CEM-7)
  - chlorine and hydrogen chloride (TM-7 and TM-8)
  - fluorine (TM-9)
  - hazardous substances (TM-12, TM-13 and TM-14)
  - solid particles (TM-15)
  - carbon monoxide (OM-1 or CEM-4)
  - volatile organic compounds (OM-2, CEM-8, CEM-9 or CEM-10)

8.2 Sampling odour from point sources

The sampling methods included in *Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales* (referenced by the Clean Air (Plant and Equipment) Regulation 1997) must be used.

Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales refers to Australian Standard or USEPA methods for:

- selecting sampling positions (TM-1)
- determining velocity and volumetric flow rate (TM-2 or CEM-6)
- determining temperature in stack gases (TM-2 or TM-15)
- determining moisture content in stack gases (TM-22)
- determining dry gas density/molecular weight of stack gases (TM-23)

- determining carbon dioxide in stack gases (TM-24 or CEM-3)
- determining oxygen in stack gases (TM-25 or CEM-3)
- determining emission concentration of odour (OM-7).

8.3 Sampling odour from diffuse sources

The draft Australian Standard does not contain guidance for sampling odours from diffuse sources. Methods currently used in Australia for sampling odours from diffuse sources include:

- isolation flux hood
- wind tunnel
- equipment enclosure (‘tent’)
- ‘witch's hat’.

The odour emission rate from a diffuse source may also be estimated by taking ambient measurements, at a known distance downwind from the source, under known meteorological conditions and using a Gaussian plume dispersion model to back calculate.

Each of the procedures has limitations, especially for various source types.

Table 8.1 is an attempt to classify the appropriateness of diffuse source sampling methods according to source type[24]. The classification process considered practical sampling issues and the methods likely to best estimate the actual odour source emission rate.

It is important to note that:

- no one method is currently considered universally applicable
- the information contained in Table 8.1 is a first attempt at categorising area source sampling methods.

Future experience and research should be used as a basis for refining the selection process and methodology.

The sampling methods included in *Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales* (referenced by the Clean Air (Plant and Equipment) Regulation 1997) must be used.

Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales refers to the USEPA method for:

- *Measurement of Gaseous Emission Rates from Land Surfaces Using an Emission Isolation Flux Chamber. User's Guide*. EPA/600/8-8E/008. February 1986 (OM-8).

Other sampling methods may be substituted for this method where there is either a valid Australian or overseas method, or sufficiently detailed protocol available for its use. However, if an alternative sampling method is proposed, the licensee must submit a proposed sampling method to the EPA and seek written approval from the EPA to use this method.

24 Clean Air Society of Australia and New Zealand Inc. *Workshop Position Paper*. Odour Special Interest Group, 2nd National Odour Workshop, March 2 & 3 1998, Cape Schank, Victoria.

Table 8.1 Diffuse source sampling methods, according to source type

Source type	Diffuse source sampling method				
	Back calculation	Wind tunnel	Flux hood	Tent	Witch's hat
Waste water treatment sources					
Aerated	x	✓	x	x	✓
Still	x	✓	✓	x	✓
Inlet works	x	✓	✓	✓	x
Anaerobic lagoon	✓	✓	✓	x	x
Trickling filter (top)*	x	x	✓	✓	x
Other sources					
Cattle feed lot	✓	x	x	x	x
Compost wind rows (static)	x	✓	✓	x	✓
Compost wind rows (aerated)	x	x	x	x	✓
Soil bed filters/biofilters	x	x	x	✓	✓
Landfills	✓	x	✓	TBD	TBD

✓ applicable sampling method for this source type

x not applicable sampling method for this source type

TBD applicability to be determined

* trickling filter base vents should be sampled concurrently as point sources.

8.4 Analysis of odour

Dynamic olfactometry provides a suitable technique for assessing odour concentrations due to complex mixtures of compounds. Odour science has recently focused on establishing improved and more repeatable measurement techniques for estimating odour concentrations using forced choice dynamic olfactometry. Dynamic olfactometry, coupled with odour dispersion modelling, can provide a reliable assessment of odour impact.

The dynamic olfactometry process

The process involves exposing a selected and controlled panel to precise variations in odour concentrations, in a controlled sequence.

The odour sample is initially diluted, so that no panellists can detect the odour. Each panellist is in turn presented with the diluted sample and asked if they can detect an odour. If not able to detect an odour, they are requested to guess from which port the odour is emanating (hence 'forced choice'). At this stage, the panellist is required to indicate their level of certainty about whether the odour was present on a scale of 1 to 6 (ranging from 'guessed' to 'absolutely sure').

The odour concentration is then increased in steps of two to three and the procedure repeated until all panellists have reported consistently correct ports with certainty. This may cover at least five dilution steps. The olfactometer is then purged with odour-free air and the procedure repeated.

Analysing the data

Using the panellist’s responses it is possible to produce two end points:

- the first end point is where one panellist is constantly correct without reference to either guessing or certainty
- the second end point is where the panellist is correct and is absolutely certain.

The panel results are analysed, using standard methods, to determine the point at which only half the panel can detect the odour. The number of odour units is the concentration of a sample divided by the number of dilutions required for the sample to reach the threshold. This threshold is the numerical value equivalent to when 50% of the panel correctly detect the odour.

The detectability or threshold of an odour is a sensory property that refers to the theoretical minimum concentration that produces an olfactory response or sensation. This point is called the odour threshold and defines one odour unit per cubic metre (OU/m^3).

Removing bias

The performance of individual panellists is monitored and those with a heightened sensitivity to odours, or with inconsistent performance, are replaced with other suitable panellists. The draft Australian and European CEN Standards require that the geometric mean of individual odour threshold estimates must fall between 20 ppb and 80 ppb for n-butanol (the reference compound).

Forced choice dynamic olfactometry is able to remove the potential human bias that may occur given that the panellists are required to indicate whether they are absolutely certain that an odour has been perceived.

Using the data for odour impact assessment

This data can be subsequently used within a dispersion model to estimate potential odour impacts for new facilities and aid in the site selection process. Using this approach, odour control strategies can also be developed for existing operations.

The measurement methods included in *Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales* (referenced by the Clean Air (Plant and Equipment) Regulation 1997) must be used.

Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales refers to Draft Australian Standard or European methods as follows:

- Draft Australian Standard – *Air quality – Determination of odour concentration by dynamic olfactometry*, Project No: EV/007-0600 (OM-7)
- European Standard – *Air quality – Determination of odour concentration by dynamic olfactometry*. (CEN) Document CEN/TC264/WG2/N222/e (OM-7).

8.5 Analytical report requirements

The results of any sampling and analysis must be provided as a summary report signed by the licence holder or, where there is no licence, by the person required to provide the report. In accordance with the requirements of *Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales*, the report must contain at least the following information for each air contaminant, unless stated otherwise:

- name and address of reporting organisation or individual

- date of issue of the report
- date, time and place of measurements
- identification of source tested
- the test method used and details of any deviation from that method
- details of source or process operating conditions during sampling and a statement about the representativeness of the sample taken
- location of sampling plane, with respect to the nearest upstream and downstream flow disturbances
- number of sampling points
- period of sampling (start and end times)
- average stack gas velocity in metres per second
- average stack gas temperature in Kelvin
- contaminant molecular weight or density in kilograms per cubic metre
- water content of stack gas, expressed as a percentage by volume
- stack gas volumetric flow rate on a dry basis under standard conditions, in cubic metres per second
- concentration of contaminant on a dry basis under standard conditions, in grams per cubic metre
- mass emission rate of contaminant on a dry basis under standard conditions, in grams per second
- details of sample preservation, if applicable
- any factors that may have affected the monitoring results
- the precision of the results (using AS 2706 as a guide)
- details of the most recent calibration of each instrument used to take measurements.

If an air contaminant cannot be detected, results must not be quoted as zero but as less than the method's limit of detection.

All volumes and concentrations are normally reported as dry at a temperature of 0°C and at an absolute pressure of 101.3 kilopascals (kPa). The EPA's monitoring requirements may also specify a reference gas level to which the result must be corrected.

8.6 References

Clean Air (Plant and Equipment) Regulation 1997

Clean Air Society of Australia and New Zealand Inc., 1998, *Workshop Position Paper*, Odour Special Interest Group, 2nd National Odour Workshop, March 2–3 1998, Cape Schank, Victoria

Committee Europe en de Normalisation, 1995, *Odour Concentration Measurement by Dynamic Olfactometry*, CEN/TC264/WG2/N222e, Odours Final WG2 Draft prEN

NSW Environment Protection Authority, 1999, *Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales*

Standards Australia, 1999, Draft Australian Standard – *Air quality – Determination of odour concentration by dynamic olfactometry*, Project No: EV/007-0600

United States Environmental Protection Agency, 1996, *Measurement of Gaseous Emission Rates from Land Surfaces Using an Emission Isolation Flux Chamber, User's Guide*, EPA/600/8-8E/008

9 Meteorological data

9.1 Minimum data requirements

It is generally accepted that a minimum of five years of site-specific meteorological data is required in order to obtain confident model predictions. As the data set is reduced, uncertainties and under-predictions in model estimates increase.

The following meteorological data specifications must be used:

1 A Level 2 odour impact assessment must use ‘synthetic’ worst-case meteorological data. Tables 9.1, 9.2 and 9.3 list the wind speed, stability class and typical mixing height combinations that need to be included in the ‘synthetic’ worst-case meteorological data file.

2 A Level 3 odour impact assessment requires at least one year of site-specific meteorological data for impact assessments based on dispersion modelling. To be deemed acceptable, a one-year, site-specific data set must be correlated against a longer duration, site-representative meteorological database of at least five years (preferably five consecutive years).

3 If site-specific meteorological data is not available for a Level 3 odour impact assessment, it is required that at least one year of site-representative meteorological data should be used for conducting impact assessments based on dispersion modelling. To be deemed acceptable, the one-year, site-representative data set must be correlated against a longer duration, site-representative meteorological database of at least five years (preferably five consecutive years).

To determine whether particular meteorological data is in fact site-representative, it must be clearly established that the data adequately describes the expected meteorological patterns at the site under investigation, e.g. wind speeds, wind direction, ambient temperature, atmospheric stability class, inversion conditions and katabatic drift.

9.2 Siting and operating meteorological monitoring equipment

The methods specified in *Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales* should be used for establishing, siting, operating and maintaining meteorological monitoring equipment.

Meteorological stations must be established, sited, operated and maintained in accordance with the following methods:

- AS 2922–1987 *Ambient air – Guide for the siting of sampling units* (AM-1).
- AS 2923–1987 *Ambient air – Guide for the measurement of horizontal wind for air quality applications* (AM-2).
- United States Environmental Protection Agency, 1987, *On-Site Meteorological Program Guidance for Regulatory Modelling Applications*, June 1987 (AM-4) EPA-450/4-87-013.

For guidance on processing meteorological data for dispersion modelling purposes, the USEPA guide (above) should be referred to.

All meteorological stations used to collect data for odour modelling should use an anemometer that has a stall speed of less than 0.5 m/s.

9.3 Level 2 and Level 3 odour impact assessment requirements

For the AUSPLUME dispersion model, the meteorological parameters required are:

- wind speed (m/s)
- wind direction (°)
- ambient temperature (°C)
- atmospheric stability class
- mixed layer height.

Wind speed, wind direction and ambient temperature can be directly measured, however, atmospheric stability class and mixed layer height need to be indirectly determined using other meteorological parameters within empirical formulae.

A meteorological station will need to measure and electronically log wind speed, wind direction and ambient temperature. In addition, for determining atmospheric stability class one of the following must be measured and electronically logged: either sigma theta (the standard deviation of the horizontal wind direction fluctuation) or total solar radiation in conjunction with temperature measurements at two levels.

As a minimum requirement, all parameters must be logged as 1 hour average values. In some circumstances and to assist in complaint confirmation, these variables may need to be averaged and logged at intervals of 10 minutes or less.

Wind speed

In dispersion modelling, wind speed is used to determine:

1 plume rise

2 plume dilution

3 mass transfer rate into the atmosphere.

Wind direction is used to approximate the direction of plume transport.

Calm wind conditions and katabatic drift

Calm wind conditions pose a special problem when estimating impacts since the Gaussian plume model assumes that concentration is inversely proportional to wind speed. It is accepted that a Gaussian plume model does not apply during calm conditions and that current knowledge regarding plume behaviour and wind patterns during these conditions is minimal. Therefore, most Gaussian plume models do not perform calculations when the source release height wind speed falls below 0.5 m/s.

Wind speeds of 0.5 m/s or less generally occur under very stable night time meteorological conditions known as katabatic drift. Stable katabatic flows are associated with distinctive terrain features such as river valleys. Katabatic or down-slope, night time winds result when the valley slope cools more rapidly than the centre through radiation heat transfer. As a result, stratification of the air takes place, with a denser layer forming close to the ground.

During these conditions, the variability of the direction of transport (plume meander) over a period of time is a major factor in estimating glcs with sufficient confidence. Due to these effects, the minimum wind speed for all dispersion modelling should not be less than 0.5 m/s.

Table 9.1 lists the minimum wind speed and stability class combinations that need to be included in the ‘synthetic’ worst-case meteorological data file used for Level 2 dispersion modelling.

Table 9.1 Wind speed and stability class combinations for Level 2 dispersion modelling

W/S	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	6	7	8	10	12	14	16	18	20
A	*	*	*	*	*	*													
B	*	*	*	*	*	*	*	*	*	*									
C	*	*	*	*	*	*	*	*	*	*	*	*	*	*					
D	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
E	*	*	*	*	*	*	*	*	*	*									
F	*	*	*	*	*	*	*												

W/S Wind speed/stability class

Ambient temperature

Ambient temperature is routinely used in dispersion models to calculate the amount of buoyancy-induced plume rise. Buoyancy-induced plume rise is proportional to a fractional power of the temperature difference between the source and the ambient air.

For Level 2 dispersion modelling, the maximum and minimum temperatures representative of the site should be included in the 'synthetic' meteorological data file to account for the range in possible plume rise. The higher temperatures will result in the lowest plume rise and in most circumstances, the largest impacts.

Stability class

Gaussian plume dispersion models use stability categories as indicators of atmospheric turbulence and, hence, the dispersive properties of the atmosphere. Based on the work of Pasquill and Gifford, seven stability categories have been defined: categories A to G represent very unstable, unstable, slightly unstable, neutral, slightly stable, stable and very stable conditions respectively. In most dispersion models, stability classes F and G are lumped within one class termed F.

The stability class at any given time depends on:

- static stability (vertical temperature profile of the atmosphere ie. migrating high and low air pressure masses)
- convective or thermal turbulence (caused by the rising of air heated at ground level)
- mechanical turbulence (a function of wind speed and surface roughness ie. wind flow over rough terrain, trees or buildings).

Three techniques are widely used to determine stability class:

- **Turner's 1964 method:** this requires information on solar altitude or zenith angle, cloud cover, cloud ceiling height and wind speed. Solar altitude can easily be calculated, however, cloud cover and ceiling height are generally determined through visual observations
- **sigma theta method** (the standard deviation of the horizontal wind direction fluctuation): all modern meteorological data loggers include software to determine sigma theta
- **solar radiation-delta temperature method** (SRDT): this retains the basic structure and rationale of Turner's 1964 method but eliminates the need for observations of cloud cover and ceiling height. The method uses the surface-layer wind speed (measured at 10 m) in combination with measurements of total solar radiation during the day and a low-level vertical temperature difference (delta T) at night.

Any of the three methods may be used to determine stability class. Table 9.1 lists the minimum wind speed and stability class combinations that need to be included in the ‘synthetic’ worst-case meteorological data file used for Level 2 dispersion modelling. The methods outlined in the USEPA guide[25] should be used for Level 3 dispersion modelling.

Mixing height

Mixing height is the depth through which pollutants released to the atmosphere are typically mixed by dispersive processes. Dispersion of pollutants in the lower atmosphere is greatly aided by the convective and turbulent mixing that takes place. Mixing height determines the vertical extent of dispersion for releases occurring below that height. Releases occurring above that height are assumed to have no ground-level impact (with the exception of fumigation episodes). Therefore, the greater the vertical extent of the mixed layer, the larger the available volume to dilute pollutant emissions.

Morning and afternoon mixing heights are estimated by using vertical temperature profiles (otherwise known as ‘upper air data’) and surface temperature measurements. For Level 3 dispersion modelling, hourly mixing heights should be estimated from the twice-daily mixing height values, sunrise and sunset times and hourly stability categories using the USEPA meteorological pre-processor for regulatory models or a processor which includes similar techniques.

However, upper air data may not be available for the site in question, therefore hourly mixing heights for use in dispersion models may be derived by using semi-empirical relationships.

For Level 2 dispersion modelling, the mixing height for neutral and unstable conditions (classes A–D) can be calculated using an estimate of the mechanically-driven mixing height. The mechanical mixing height, h, can be calculated as follows:

Equation 9.1, mechanical mixing height for stability classes A–D

$$h = 0.3 \times u^* / f$$

h mixing height (m)

u* friction velocity (m/s)

f Coriolis parameter.

For Level 2 dispersion modelling, the mixing height, h for stable conditions (classes E-F) can either be set at an unlimited value (e.g. 5000 metres), or calculated as follows:

Equation 9.2, mechanical mixing height for stability classes E–F

$$h = 0.4 \times (u^* / (1/L \times f))^{0.5}$$

h mixing height (m)

u* friction velocity (m/s)

L Monin-Obukhov length (m)

f Coriolis parameter.

Monin-Obukhov length

The Monin-Obukhov length (L) characterises the stability of the surface layer. The surface layer is defined as the layer above the ground in which the vertical variation of heat and momentum flux is

25 United States Environmental Protection Agency, 1987, *On-Site Meteorological Program Guidance for Regulatory Modelling Applications*, EPA-450/4-87-013.

negligible. The surface layer is typically 10% the height of the mixed layer. The parameter L can be calculated using the linear approximation to Golder's plot[26] as follows:

Equation 9.3, Monin-Obukhov length

$$1/L = X + Y \times \mathrm{Log}_{10}(Z_o)$$

L	Monin-Obukhov length (m)
X & Y	Parameters dependant on the Pasquill-Gifford stability class (see Table 9.2)
Z_o	surface roughness height (m) (see Table 9.3)

Table 9.2 Parameterisation of Golder's plot

	Pasquill-Gifford stability class					
Parameter	**A**	**B**	**C**	**D**	**E**	**F**
X	-0.096	-0.037	-0.002	0.000	0.004	0.035
Y	0.029	0.025	0.018	0.000	-0.018	-0.0365

In Equation 9.3 above:

- the value of Z_o is the surface roughness height, unless the surface roughness height is outside of the range of Z_{omin} to Z_{omax} presented in Table 9.3
- if the surface roughness height is less than Z_{omin} then the value of Z_{omin} should be used for Z_o
- if the surface roughness is greater than Z_{omax} then the value of Z_{omax} should be used for Z_o.

Table 9.3 Upper and lower limits for surface roughness heights for each Pasquill-Gifford stability class

	Pasquill-Gifford stability class					
Parameter	**A**	**B**	**C**	**D**	**E**	**F**
Z_{omin}	0.001	0.001	0.001	0.001	0.001	0.001
Z_{omax}	18.0	30.0	1.25	50.0	1.6	9.0

Typical values of surface roughness height for various land-uses are presented in Table 9.4.

26 Golder, D., 1972, *Relations Among Stability Parameters in the Surface Layer*, Boundary Layer Meteorology, Volume 3

Table 9.4 Typical values of surface roughness height for various land-use categories (AUSPLUME version 4.0)

Land-use category	Roughness height – Z_o (m)	Land-use category	Roughness height – Z_o (m)
Hills	2.0	Highrise	1.0
Industrial areas	0.8	Commercial	0.8
Forest	0.8	Residential	0.4
Rolling rural	0.4	Flat rural	0.1
Flat desert	0.01	Water	0.0001

Surface friction velocity

The surface friction velocity u* is a measure of mechanical turbulence and is directly related to surface roughness. The parameter u* can be calculated using the procedure presented below (California Institute of Technology (CIT)[27]).

Condition 1: wind speed equal to 0

$u^* = 0.001$ m/s

Condition 2: unstable conditions (Pasquill-Gifford stability classes A, B, C or 1/L < 0)

$u^* = VK \times W_{sp} / \phi$

- u* surface friction velocity (m/s)
- VK Von Karman constant; use a value of 0.4
- W_{sp} absolute value of the wind speed at height Zr (m/s)
- ϕ calculated according to the following equation:

$$\phi = \mathrm{Log}_{10}(Z_r / Z_o) + \mathrm{Log}_{10}((PZ_o^2 + 1.0) \times (PZ_o + 1.0)^2 / ((PZ_r^2 + 1.0) \times (PZ_r + 1.0)^2)) + 2 \times (\tan^{-1}(PZ_r) - \tan^{-1}(PZ_o))$$

- Z_r reference height for the wind measurements (m)
- Z_o surface roughness height (m)
- PZ_o & PZ_r calculated according to the following equations:

$$PZ_r = (1.0 - 15.0 \times Z_r / L)^{0.25}$$

$$PZ_o = (1.0 - 15.0 \times Z_o / L)^{0.25}$$

- Z_r Reference height for the wind measurements (m)
- Z_o Surface roughness height (m)
- L Monin-Obukhov length (m).

27 McRae, G. J., 1981, *Mathematical Modelling of Photochemical Air Pollution*, Chapter 4 ‘Turbulent Diffusion Coefficients’, PhD Thesis, California Institute of Technology

Condition 3: neutral conditions (Pasquill-Gifford stability class D or 1/L = 0)

$u^* = VK \times W_{sp} / Log_{10}(Z_r/Z_o)$

u^*	surface friction velocity (m/s)
VK	Von Karman constant; use a value of 0.4
W_{sp}	absolute value of the wind speed at height Z_r (m/s)
Z_r	reference height for the wind measurements (m)
Z_o	surface roughness height (m).

Condition 4: stable conditions (Pasquill-Gifford stability class E or F or 1/L > 0)

$u^* = VK \times W_{sp} / (Log_{10}(Z_r / Z_o) + 4.7 / L \times (Z_r - Z_o))$

u^*	surface friction velocity (m/s)
VK	Von Karman constant; use a value of 0.4
W_{sp}	absolute value of the wind speed at height Z_r (m/s)
Z_r	reference height for the wind measurements (m)
Z_o	surface roughness height (m).

Coriolis parameter

The Coriolis parameter accounts for wind direction variation with height (wind shear) at different latitudes and can be calculated in accordance with well-established techniques[28].

The Coriolis parameter (f) can be calculated as follows:

f $2\Omega \sin(\phi)$

Ω	earth's rotation rate ($2\pi/86400$ or 7.29×10^{-5} rad.s^{-1})
π	pi or 3.1416 radians (rad)
86400	number of seconds in the day (s)
ϕ	latitude in radians (rad).

Table 9.5 lists an example of typical mixing heights for a location with similar latitude to Sydney (34°) and in a rural location (surface roughness height of 0.3 metres) to be included in the 'synthetic' worst-case meteorological data file.

28 Zanetti, P, *Air Pollution Modelling: Theories, Computational Methods and Available Software*, Van Nostrand Reinhold, New York

Table 9.5 Typical mixing heights for a rural location

	Mixing height combinations used for Level 2 (x 10^3)																		
W/S	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**6**	**7**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
A	0.2	0.4	0.6	0.8	1.0	1.2													
B	0.2	0.4	0.5	0.7	0.9	1.0	1.2	1.4	1.6	1.8									
C	0.2	0.3	0.5	0.6	0.8	0.9	1.1	1.2	1.4	1.5	1.8	2.1	2.4	3.1					
D	0.2	0.3	0.4	0.6	0.7	0.8	1.0	1.1	1.3	1.4	1.7	2.0	2.2	2.8	3.3	3.9	4.5	5.0	5.0
E	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0									
F	5.0	5.0	5.0	5.0	5.0	5.0	5.0												

W/S Wind speed/stability class

Table 9.6 lists an example of typical mixing heights for a location with similar latitude to Sydney (34°) and in an urban location (surface roughness height of 1.0 metres) to be included in the 'synthetic' worst-case meteorological data file.

Table 9.6 Typical mixing heights for an urban location

	Mixing height combinations used for Level 2 (x 10^3)																		
W/S	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**6**	**7**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
A	0.3	0.6	1.0	1.3	1.6	2.0													
B	0.3	0.5	0.8	1.1	1.4	1.7	1.9	2.2	2.5	2.7									
C	0.2	0.4	0.7	0.9	1.1	1.3	1.5	1.8	2.0	2.2	2.6	3.1	3.5	4.4					
D	0.2	0.4	0.6	0.8	1.1	1.3	1.5	1.7	1.9	2.1	2.6	2.9	3.4	4.3	5.0	5.0	5.0	5.0	5.0
E	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0									
F	5.0	5.0	5.0	5.0	5.0	5.0	5.0												

W/S Wind speed/stability class

9.4 Processing meteorological data for Level 3 odour impact assessments

Meteorological data for dispersion modelling purposes should be prepared using the techniques outlined in the USEPA guide[29].

Meteorological data for dispersion modelling purposes should be processed using the USEPA software package[30].

29 United States Environmental Protection Agency, 1987, *On-Site Meteorological Program Guidance for Regulatory Modeling Applications*, EPA-450/4-87-013

30 United States Environmental Protection Agency, 1996, *Meteorological Processor for Regulatory Model (MPRM), User's Guide*, EPA-454/B-96-002

9.5 Availability of meteorological processing software and guidance documents

Meteorological processing software and guidance documents can be electronically downloaded, free of charge, from the USEPA website: www.epa.gov/ttn/scram/.

9.6 References

McRae, G. J., 1981, *Mathematical Modelling of Photochemical Air Pollution*, Chapter 4 'Turbulent Diffusion Coefficients', PhD Thesis, California Institute of Technology

NSW Environment Protection Authority, 1999, *Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales*

Standards Australia, 1987, AS 2922–1987, *Ambient air – Guide for the siting of sampling units*

Standards Australia, 1987, AS 2923–1987, *Ambient air – Guide for the measurement of horizontal wind for air quality applications*

United States Environmental Protection Agency, 1996, *Meteorological Processor for Regulatory Model (MPRM), User's Guide*, EPA-454/B-96-002

United States Environmental Protection Agency, 1987, *On-Site Meteorological Program Guidance for Regulatory Modeling Applications*, EPA-450/4-87-013

Zanetti, P., *Air Pollution Modelling: Theories, Computational Methods and Available Software*, Van Nostrand Reinhold, New York

10 Dispersion modelling

10.1 Introduction

Predicting the impact on a given site due to a variety of odour sources requires estimating:

- odour emission rates and their variability
- glcs at key sensitive receptors (and likely future sensitive receptors) due to each emission source for all hours of an extensive meteorological database
- some superposition of the ambient odour levels due to each source
- community reaction to the predicted odour exposure.

Odour exposure statistics are conventionally evaluated by a combination of emission estimation and dispersion modelling. Odour additivity and offensiveness are usually only known from experience or intensive odour surveys.

Emission estimates are generally based on a small sample of odour measurements (for an existing facility) or on emission models derived from past surveys at similar facilities. Emission statistics (other than typical or maximum levels) are rarely available, especially for area sources.

Emission rates are used in an air dispersion model to give a predicted spatial distribution of odour intensity or constituent concentration throughout the area of interest for a given set of meteorological conditions.

Widely used dispersion models (e.g. AUSPLUME) are generally employed to predict mean (ie. 1 hour average) rather than peak (ie. 1 second) concentrations.

Therefore, additional assumptions are required for estimating both emissions and peak concentrations to predict odour exposure statistics.

Estimating odour impacts from existing sources

Community odour annoyance around existing sources can be assessed by analysing detailed residential surveys and any long-term diaries of significant events. The sources of offending odour can be determined from detailed sensory, chemical and meteorological investigations. Over time, the success of odour control methods can be directly assessed, assuming no change in community sensitivity.

The spatial distribution of annoyance may be determined by analysing extensive community surveys or extrapolating existing complaints data using available emissions information, a reliable site-specific meteorological database and a validated dispersion model.

Estimating odour impacts from new sources

When evaluating likely odour from new sources, it is unlikely there will be a sufficient number of experienced observers available to warrant using the methods described above. Predictions have to rely on mathematical modelling to a much greater extent.

The essential data requirements are:

- a suitable classification of odour sources, including the offensiveness and interaction of their odours and the dependence of emission rates on process and meteorological conditions

- an acceptable methodology for forecasting the likely time-varying emission rates of all significant odour sources
- a long-term detailed meteorological database (e.g. one year of hourly measurements of wind, temperature and atmospheric stability) at or near the planned site
- an acceptable estimation process for evaluating the spatial distribution of odour for each hour of a one-year period (minimum), accounting for the variety of source characteristics, local topographic effects and the locations and characteristics of sensitive receptors (and likely future sensitive receptors)
- estimates of community odour sensitivities that take into account the wide variety of individual responses and community attitudes to the perceived costs and benefits of the proposed project.

Limitations of dispersion models

Dispersion models are commonly used for estimating the spatial distribution of odour. When using dispersion models it is important to take into account that techniques for estimating and measuring concentration fluctuations over a short time period are still in their infancy. Significant field work and model testing has been performed only in recent years and this has mainly been concerned with the dispersion of explosive or toxic compounds rather than odours.

Dispersion models are only beginning to come to grips with the forecasting of ‘average’ concentrations (typically over 1 hour of steady state meteorology). Even so, the natural variability caused by atmospheric turbulence and imprecise input parameters can limit the accuracy of a good model to within ± 50% to 100% for a given hour. However, standard dispersion models such as AUSPLUME are considered to be reasonable tools that can be used to predict behaviour over a large number of like events (the ensemble of realisations).

A set of rules for estimating peak concentrations from predicted ensemble averages is a useful adjunct to standard modelling techniques.

10.2 Level 2 and Level 3 odour impact assessment methodology

1 List all potential odour sources

Include all sources within the site boundary and any nearby sources beyond the boundary if it is possible they could contribute to cumulative odour impacts.

2 Gather data for each release point

For each release point:

- determine whether the odour release is point or diffuse. Select point, area or volume source options within the chosen dispersion model
- determine the location, elevation and discharge geometry
- determine source location coordinates in metres relative to a fixed origin
- To account for building wake effects, determine the location and dimensions of buildings within a distance of 10L from each release point, where L is the lesser of the height or width of the building.

3 **Determine appropriate environmental outcome**

If the odour is due to individual odorous compounds, select the appropriate glc criteria from chapter 2.

If the odour is due to a complex mixture, select the appropriate odour performance criteria as a function of population density, from chapter 3.

4 **For new proposals:**

Estimate emission quantities

For individual odorous compounds (glc criteria) or complex mixtures (odour performance criteria) use published emission factors/data from similar operations and/or manufacturers' performance guarantees.

The emission factors/data should have been developed in a manner consistent with the odour sampling and analysis methods detailed in chapter 8:

- for individual odorous compounds (glc criteria) determine mass emission rates in grams per second
- for complex mixtures (odour performance criteria) determine mass emission rates in OU per second
- if applicable, include periodic variations in emission rates.

Estimate source release parameters

Use published source release parameters and/or manufacturers' performance guarantees:

- for point sources determine stack height, stack diameter, temperature and velocity
- for diffuse area sources determine surface area, side length and release height
- for diffuse volume sources determine side length and release height.

5 **For existing plant:**

Estimate emission quantities

For individual odorous compounds (glc criteria) or complex mixtures (odour performance criteria) use site-specific measured concentrations.

The emission rates should be determined using the sampling and analysis methods detailed in chapter 8:

- for individual odorous compounds (glc criteria) determine mass emission rates in grams per second
- for complex mixtures (odour performance criteria) determine mass emission rates in OU per second
- if applicable, include periodic variations in emission rates.

Estimate source release parameters

Use site-specific measurements of source release parameters

- use sampling and analysis methods discussed in chapter 8
- for point sources, determine stack height, stack diameter, temperature and velocity
- for diffuse area sources determine surface area, side length and release height
- for diffuse volume sources determine side length and release height.

6 Incorporate other dispersion modelling parameters

Select appropriate peak-to-mean ratios for each source type from Table 10.1.

Develop gridded data for terrain and receptors, including location and height in metres relative to a fixed origin.

Include the location of any particularly sensitive receptors (and likely future sensitive receptors) such as residences, schools, hospitals etc.

Develop either a synthetic worst case or a site-specific meteorological data file. The data file should include hourly average values for:

- wind speed
- wind direction
- ambient temperature
- atmospheric stability class and mixing height

in accordance with the methods outlined in chapter 9.

7 For new or existing plant, select a number of scenarios for analysis

To determine incremental increases in the cost of abatement, carry out a sensitivity analysis by varying:

- source release parameters
- efficiency of pollution control equipment
- level of management practice or
- separation distance.

Use the results to select the most cost-effective and environmentally-effective control strategy.

8 Prepare dispersion model input files and run computer-based model

When selecting a dispersion model, it is important to ensure that the model is able to differentiate between different source types. As well as using the model to calculate hourly mean concentrations, the model should be able to estimate peak concentrations, particularly when the results will be used to evaluate complaints about odour.

9 Process dispersion model output files

Use utilities provided with AUSPLUME, such as AUSPSTAT.EXE to prepare gridded files of ground-level concentration statistics.

10 Analyse dispersion model results

For Level 2 odour impact assessments, determine the **100**th percentile dispersion model predictions for glc or odour performance criteria

For Level 3 odour impact assessments, use statistical analysis to determine either

- **99.9**th percentile **3 minute** average dispersion model predictions for glc criteria, or
- **99**th percentile **nose response time** average predictions for odour performance criteria.

Use graphical techniques to prepare odour concentration contours (isopleths) to define potential affected zones.

Tabulate the odour predictions at each of the existing and likely future sensitive receptors and at the most exposed off-site receptor. Compare the predictions with the glc or odour performance criteria.

11 What to include in a Level 2 and Level 3 odour impact assessment report

The dispersion modelling and impact assessment report must contain the information requirements specified below:

Site plan

- layout of the site clearly showing all unit operations
- all emissions sources clearly identified
- plant boundary
- sensitive receptors (e.g. nearest residences)
- topography

Description of the activities carried out on the site

- process flow diagram clearly showing all unit operations carried out on the premises
- detailed discussion of all unit operations carried out at the site, including all possible operational variability
- detailed list of all process inputs and outputs
- plans, process flow diagrams and descriptions which clearly identify and explain all pollution control equipment and pollution control techniques for all processes on the premises
- description of all aspects of the air emission control system, with particular regard to any fugitive emission capture (e.g. hooding, ducting), treatment (e.g. scrubbers, bag filters etc.) and discharge systems (e.g. stack)
- operational parameters of all potential emission sources, including all operational variability, ie. location, release type (e.g. stack, volume or area) and release parameters (e.g. stack height, stack diameter, exhaust velocity, temperature, emission rate) and process type (e.g. batch or continuous).

Description of level 3 meteorological data

- detailed discussion of the prevailing dispersion meteorology at the proposed site. The report should typically include wind rose diagrams and an analysis of wind speed, wind direction, stability class, ambient temperature and joint frequency distributions of the various meteorological parameters
- description of the techniques used to prepare the meteorological data into a format for use in the dispersion modelling
- QA/QC analysis of the meteorological data used in the dispersion modelling. Any relevant results of this analysis should be provided and discussed
- meteorological data used in the dispersion modelling supplied in a suitable electronic format

Description of level 2 meteorological data

- description of the techniques used to prepare the meteorological data into a format for use in the dispersion modelling
- meteorological data used in the dispersion modelling supplied in a suitable electronic format.

Emission inventory

- detailed discussion of the methodology used to calculate the expected pollutant emission rates for each source
- all supporting source emission test reports etc. (Note: all analytical reports must contain all the information specified in Section 4 of *Approved Methods for the Sampling and Analysis of Air Pollutants in New South Wales*)
- methodologies used for the sampling and analysis for each of the pollutants considered
- detailed pollutant emission rate calculations for each source
- a table showing all stack and fugitive source release parameters (e.g. temperature, exit velocity, stack dimensions and emission rates)

Dispersion modelling

- detailed discussion and justification of all parameters used in the modelling, and the manner in which topography, building-wake effects and other site-specific peculiarities which may effect plume dispersion have been treated
- detailed discussion of air quality impacts for all relevant pollutants, based upon predicted ground-level concentrations (glcs) at the plant boundary and beyond and at all sensitive receptors
- glc isopleths (contours) and tables summarising the predicted concentrations of all relevant pollutants at sensitive receptors
- all input, output and meteorological files used in the dispersion modelling supplied in hard copy and suitable electronic format.

Site-specific emission limits

- all calculations and data relating to the derivation of site-specific emission limits.

Calculating emission rates for Level 2 and Level 3 odour impact assessments

If the source is large, the frequency distribution of emission rates should be compiled and used in conjunction with the frequency distribution of meteorological conditions, to predict the overall frequency distribution of predicted ground-level concentrations.

If the source is smaller and data is available to describe the distribution of emissions, use the 99.9th percentile.

If no data is available to describe the emission rate distribution, use the maximum measured or calculated emission rate.

Where practicable, emission rate data should be constructed using an averaging period which is the lesser of

- one hour, or
- the sampling time used in the concentration calculations.

Developing odour emission rate models for Level 3 odour impact assessments

An odour emission rate model should take into account the following factors, or any other factors that are unique to a particular industry:

- the hours of operation of the facility

- whether the process or activity is batch or continuous in nature
- whether emissions vary as a function of:
  - process conditions (e.g. temperature, pressure etc.)
  - production rate
  - hour of the day, week, month or season
  - meteorological variables (e.g.wind speed, ambient temperature, humidity, atmospheric stability class, rainfall etc)
  - feedstock
  - animal age or feed type.

This is not intended to be an exhaustive list and the key parameters will be specific to the industry in question. Contact the EPA before developing or using these emissions models, to ensure the proposals are consistent with the requirements of this policy.

10.3 Why peak-to-mean ratios are needed

It is commonly recognised that dispersion models such as AUSPLUME need to be supplemented to accurately simulate atmospheric dispersion of odours. This is because the instantaneous perception of odours by the human nose typically occurs over a time scale of approximately one second but dispersion model predictions are typically valid for time scales equivalent to ten minutes to one hour averaging periods.

To estimate the effects of plume meandering and concentration fluctuations perceived by the human nose, it is possible to multiply dispersion model predictions by a correction factor called the 'peak-to-mean ratio'.

A detailed investigation was undertaken by Katestone Scientific Pty Ltd in 1995 on behalf of the NSW EPA and supplemented with further work in 1998. This study has provided estimates of peak-to-mean ratios for point and diffuse sources of odour as a function of source type, atmospheric stability class and downwind distance from the source. This data can be incorporated into a dispersion model to estimate the instantaneous concentrations of odours that may be detected by the human nose.

The following sections detail the methodology recommended for predicting peak (few second) odour intensities from hourly average dispersion model predictions, for use in assessing odour annoyance for new and existing sources. More detailed explanations, references and specific experimental work are discussed in supporting technical reports (Katestone Scientific 1995, 1998).

10.4 Definitions of terms

The scientific terminology for characterising fluctuations is complex. The following sections provide definitions for the following terms:

- peak concentration
- mean concentration
- peak-to-mean ratio
- intensity of fluctuations
- point source
- area source

- line source
- volume source
- tall stack
- wake-affected stack
- source types
- zones of influence

Concentration measures

Peak concentration

Typical time series of concentrations of a gaseous pollutant over short time scales and for different source and atmospheric conditions show that the non-zero concentrations are very intermittent (ie. the data record consists of irregularly spaced ‘peaks’ or ‘singularities’). The time scales involved with the peak depend mainly on the resolution of the instrumentation (greater resolution yields finer structure).

For locations very close to the source, there may be an upper limit to the peak concentration (ie. the no dilution case, when short-lived pockets of odour-generating material remain within the plume and so the source emission rate is essentially constant on short time scales). Further downwind there is no effective maximum concentration and the value of the peak concentration measured depends on the time resolution and the period of observation. For odour design purposes, the peak concentration is best considered as the maximum concentration that is exceeded no more than a specified percentage of time (e.g. choosing a 10^{-3} exceedance level).

Mean concentration

The mean concentration refers more to the predictable concentration at a given point for an averaging period long enough to reduce stochastic variability to a reasonable level. The generalisations used in most practical models for mean concentrations (such as profile and turbulence parameters) are only valid for an ensemble of realisations. There is an increasing inherent uncertainty (caused by the imprecise specification of turbulence and wind fields) with decreasing averaging time.

Dispersion models are thought to predict hourly averages relatively accurately as long as it is recognised that predictions are for the stochastic average over all input conditions consistent with the specification of emission and meteorological conditions (ie. over an ensemble of realisations of the process). As ensemble averages can only be well-approximated by averages over many time periods of atmospheric motion, the reference time period for mean concentration predictions must be carefully chosen (and is almost certainly <u>not</u> 3 minutes). For convective conditions the relevant time scale is approximately 3 to 5 minutes and hourly averages are a sensible choice. For stable conditions, the time scale may be considerable if mesoscale eddies are present and the averaging period will be at least one hour.

Peak-to-mean ratio

The peak-to-mean ratio is the peak concentration divided by the mean concentration.

An averaging period of 1 hour is recommended for all dispersion modelling. When using the results of dispersion models, it is convenient to denote P/M60 as the ratio of peak concentrations to 1 hour averages.

Intensity of fluctuations

The concentration characteristics at a given location are well represented by the probability distribution. This data is rarely available although the lower order moments [mean C_m, variance σ_c^2, skewness (S) and kurtosis (K)] may be measured. The form of the probability distribution is often assumed from previous field and laboratory experiments to be:

- one parameter (e.g. exponential)
- multi parameter (e.g. normal, log normal, clipped normal, clipped gamma, Weibull), or
- more complex distributions (e.g. conjugate beta, K distributions).

Many of these distributions are characterised by a location parameter, ie. the mean concentration C_m and the standard deviation σ_c (the 'volatility'). More information about the occurrence of peaks within the concentration records is contained within the higher order moments and other measures such as the intermittency, recurrence interval, burst and gap lengths. A simple descriptor such as the intermittency (γ, the fraction of the time record with a non-zero concentration) is usually related to the intensity of concentration fluctuations ($i = \sigma_c / C$), both overall and in the plume (i_p).

Experimental and theoretical analyses often concentrate upon the overall intensity of fluctuations. If the form of the probability distribution is assumed, the likelihood of a concentration n times the mean can be estimated. The peak to mean ratio (P/M) is then given at a specified risk of exceedance.

Source structure

Whichever method is used to evaluate peak and mean concentrations, it is necessary to evaluate source structure. In practice, overall source configuration may be simply one of the following types, or a combination of different source structures and/or different pollutants.

Point source

For a point source, emissions emanate from a very small volume, therefore detailed source structure is unimportant. Elevated point sources will be referred to as stack sources (see below).

Area source

An area source has a more realistic two-dimensional structure but only a limited vertical extent.

Line source

A line source is a special case of a long, thin area source. In practice, these sources are taken to be at ground level and thin.

Volume source

A volume source is an essentially three-dimensional structure. Usually there are a sufficient number of emission points to consider a uniform emission rate over the full source structure.

Tall stack

An elevated source is usually a stack. Stacks have relatively small horizontal dimensions and usually emit hot gases forcefully into the atmosphere at a fixed height above ground level. The term 'tall' stack usually refers to stacks that protrude out of the surface boundary layer (e.g. over 30 to 50 m tall).

Wake-affected stack

Wake-free stacks are sufficiently high (2.5 times the largest nearby building) so that the stack top airflow is not influenced by surrounding buildings.

If nearby buildings can interfere with the trajectory and growth of the stack plume, the source is called a wake-affected stack. For stack heights up to 2.5 times the surrounding building heights, wake effects may be significant, depending on source characteristics. Such intermediate cases should be dealt with on an individual basis.

Source types

In the absence of any parametric representation of past results, the following approximations are recommended:

- A line source becomes an area source if the breadth exceeds 20% of the length.
- A point source requires fairly equal lateral dimensions that are very small compared to the distance to the nearest receptor.
- Tall wake-free stack sources extend over 30 m above the ground and are not likely to suffer aerodynamic downwash.
- Wake-affected stack sources have a release height less than a factor of 2 below the height of the nearest building (ie. a building located within 10 stack heights).
- Sources are no longer to be considered separate if their separation is less than one tenth of the typical boundary layer height or downwind distance to the nearest receptor.

These guidelines are very approximate but a better representation requires more knowledge about boundary layer characteristics than is usually available.

Zones of influence

Regarding plume behaviour, the location of downstream receptors is classified into three different zones of influence:

- The **near field** is the zone where source structure directly affects plume dispersion and structure. The near field is typically 10 times the largest source dimension, either height or width.
- The **mid field** region is the zone where source characteristics are important but not dominant.
- The **far field** region is the zone where plume rise and meandering have fully occurred and the plume is well mixed in the vertical plane from ground level to the base of the first temperature inversion. In the far field any mathematical expressions for the intensity, i(x), for different surface source characteristics should become similar.

The location of these three zones will depend on atmospheric conditions.

10.5 Basic approach for estimating offensive odour impacts

Estimating emissions

In practice, odour emission rates from agricultural holdings, sewage treatment plants, ponds and irrigated land may vary considerably due to fluctuations in wind, temperature and process or animal activity. Modelling of hourly average odour concentrations should forecast mean concentrations for a constant source emission rate (suitably adjusted for meteorological and process dependencies) and also allow for the variability i_E in intensity caused by short-time-scale fluctuations in emission rates.

If it is assumed that the emission and meteorological/dispersive fluctuations are independent, then the total intensity of fluctuations will be given by:

$$i_{tot}^2 = i^2 + i_E^2$$

For $i_E = 0.2$, the change in total intensity is typically less than 10%, for i between 0.5 and 1.5.

The emission variability becomes important if i_E becomes comparable to i (e.g. for an area source under stable conditions).

From a practical point of view, for agricultural sources it is important to ensure the emission rate E is properly adjusted for the pertaining meteorological conditions for a given hour, e.g. wind speed, temperature, rainfall and where animals are involved, the time of day in relation to animal behaviour.

Prescribing concentration intensity

Improving on past recommendations, i_{tot} and the form of the probability distribution should be prescribed as a function of downwind distance, stability and source type.

Past studies provide guidance about the centreline variation of i(x), the effects of source size and the applicability of laboratory and numerical studies to realistic situations. Numerical modelling results indicate the differences between point, area and line sources and suggest useful empirical prescriptions for i(x). Wind tunnel results have been used to determine the likely extent of near field, mid field and far field zones.

Katestone Scientific (1995) provided information for each source type, such as:

- approximate prescriptions of the location and magnitude of the maximum centreline intensity of fluctuations (x_{max} and i_{max})
- locations of near field and far field zones
- realistic choices for probability distribution
- approximate values of p.

This was extended in Katestone Scientific (1998) to give profiles for i(x).

For each source type, the detailed results forming the basis for the screening values shown in Table 10.1 have been used to determine sensible three parameter fits for i(x), based on prescriptions for i_{max}, x_{max} and the far field value i_f for large downwind distances. (See 10.7).

Estimating peak concentrations

With suitable definitions of source type and by selecting the probability distribution $\wp(x)$ and an exceedance rate, P/M values can be used to estimate peak concentrations for a particular set of source and meteorological characteristics. For odour evaluations, the procedure can be repeated to obtain peak odour levels at each receptor for all times in the meteorological data file (See Figure 10.1.).

Estimating odour response

Response statistics can be generated from the number of events exceeding a chosen threshold (this can be made receptor-specific) or by more complex post-processing procedures. For example, for a specified regulatory requirement of more than 99% of hours without annoyance events, you can calculate to what extent control options like optimising plant design could be employed to keep within the threshold.

Caveats

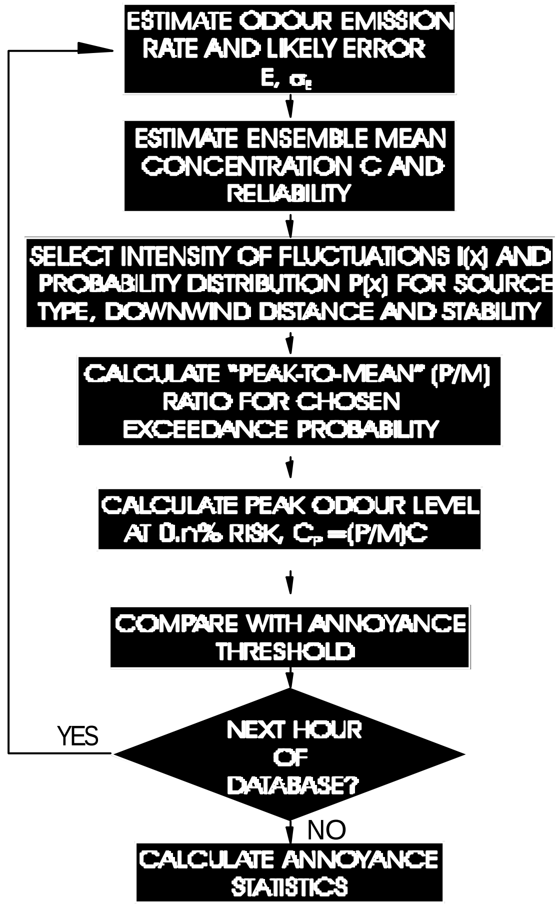
This procedure is relatively straightforward for individual sources. However, for multiple sources the degree of interaction between the sources will influence the total concentration intensity, so the procedure may become more cumbersome. Due to masking by one component, overlapping odour sources may not give rise to additive effects.

Alternative screening procedure

A simpler method for predicting odour levels from multiple sources involves multiplying the emission rate by the corresponding maximum P/M ratio. This gives an effective source strength for use in dispersion modelling of hourly events. At each receptor, the model output for a given hour for each source can be used, assuming:

- the most prominent contribution is used, or
- if the odour source characteristics are similar and the source separation is less than a multiple of the downwind distance from the source, the contributions can be added.

Figure 10.1 Recommended odour impact assessment procedure using peak-to-mean ratios



10.6 Detailed procedure for estimating offensive odour impacts

1. Use a conventional dispersion model to estimate hourly mean concentrations from hourly averaged meteorological parameters (usually the smallest averaging time available).
2. Select the most reasonable values of i(x) and i_E to derive i_{tot} (x).
3. Utilise the i(x)/probability function approach, assuming that the ensemble mean corresponds to the model prediction, to evaluate P/M60 for all relevant values of *x* along the centreline of the plume.
4. For off-axis values, assume a distribution i(x,y) with off-axis distance and repeat step 3.
5. For the chosen exceedance probability, evaluate the peak concentration C_p for the hour.
6. Repeat the calculations for each hour of the emission and meteorological data set to obtain the probability of C_p exceeding chosen thresholds. Any exposure profiles can be incorporated at this stage (with suitable assumptions of indoor/outdoor concentrations, as necessary).
7. Present these exceedance curves together with a rating of odour offensiveness to determine whether the predicted impacts will comply with the odour performance criteria.

10.7 Screening procedure for estimating offensive odour impacts

In many situations there may be no need to proceed with the full procedure as outlined above. It may be advisable early in the assessment process to identify which of several sources is likely to dominate peak concentrations. A simple screening process is therefore useful.

For screening calculations, the results for each source type can be taken to provide approximate values for:

- location and magnitude of the maximum centreline intensity of fluctuations (x_{max} and i_{max})
- the locations of near field and far field zones
- the choice of a suitable time-averaging exponent *p* for the required distance and exposure ranges.

Table 10.1 identifies conditions for which guiding measurements are available. For other situations (e.g. convective conditions for area and line sources), the values for neutral conditions are suitable defaults. Tall point sources are not expected to give rise to significant concentrations for stable conditions in flat terrain but values for neutral conditions have been used as defaults. To a first order approximation, wake effects are assumed to be similar for neutral and convective conditions and very unlikely for stable atmospheric states. The values for volume sources can be assumed to be the same as those for wake-affected point sources.

When more information becomes available, it will be possible to determine the dependence of i(x) on dimensionless ratios such as:

- plume travel time to boundary layer time scale
- source size to boundary layer horizontal length scale
- source height to observer height
- source height to boundary layer depth
- crosswind distance to time-averaged plume width.

This information is unlikely to be available for several years.

Table 10.1 Factors for estimating peak concentrations in flat terrain

The following table shows recommended factors for estimating peak concentrations for different source types, stabilities and distances, for use in screening procedures for flat terrain situations.

Source type	Pasquill-Gifford stability class	Near field i_{max}	Near field x_{max}	Near field P/M60	Far field i	Far field P/M60
Area	D	0.5	500 to 1000	2.5	0.4	2.3
	E,F	0.5	300 to 800	2.3	0.3	1.9
	A,B,C	0.5	500 to 1000	2.5	0.4	2.3
Line	D	1.0	350	6	0.75	6
	E,F	1.0	250	6	0.65	6
	A,B,C	1.0	350	6	0.75	6
Surface point	D	2.5	200	25	1.2	5 to 7
	E,F	2.5	200	25	1.2	5 to 7
	A,B,C	2.0	1000	12	0.6	3 to 4
Tall wake-free point	D	4.5	5 h	35	1.0	6
	E,F	4.5	5 h	35	1.0	6
	A,B,C	2.3	2.5 h	17	0.5	3
Wake-affected point	A – F	0.4	–	2.3	0.4	2.3
Volume	A – F	0.4	–	2.3	0.4	2.3

i_{max} maximum centreline intensity of concentration.

x_{max} approximate location of imax in metres.

P/M60 P/M ratio for long averaging times (typically 1 hour), at a probability of 10^{-3}

h stack height.

Default values are given for area and line sources in convective conditions, tall wake-free point sources in stable conditions, wake-affected sources in convective conditions and volume sources in all stabilities. These values may be updated as more information becomes available.

10.8 Worked examples

Three practical examples are set out here, to help explain the recommended procedures.

Example 1: Major industry, tall stack source

Scenario

A major industry emits combustion gases from a 200 m high stack located close to main buildings 50 m high. The nearest residences are located 500 m away. What is the likelihood of odour nuisance occurring for normal operations with essentially constant emission characteristics?

Discussion

The good engineering practice of using a stack height over 2.5 times the building height has been observed. Therefore, interactions between the stack plume and the aerodynamically-disturbed zone close to the building are unlikely and the clear projection of the stack plume is assured. The source might cause intermittent short-lived concentrations of sulphur dioxide at the nearest residences during daytime convection.

The relative closeness of the receptors to the source is important for considering the impacts due to both mean and peak concentrations. In general, downwind zones are divided into near field, mid field and far field cases. Peak-to-mean ratios are usually different in each zone. In this example the nearest receptor is within 10 stack heights (2000 m) of the source, so we are dealing with a near field situation.

A dispersion model such as AUSPLUME will show that, for most stack volume flow rates, the highest mean concentrations at 1500 m downstream occur in convective (stability class A) conditions. Under these conditions, thermal downdrafts with vertical velocities of 2 to 3 m/s may occur for short periods of time and bring the plume to ground within 10 seconds of plume travel time (e.g. within 300 m for a 3 m/s horizontal wind), unless the plume is very buoyant. Therefore, peak concentrations may occur at different locations to maximum mean concentrations.

Table 10.1 indicates that, for convective conditions, the intensity of concentrations reaches a maximum value of 2.3 at 2.5 h = 500 m, with a peak-to-mean ratio of 17. If the hourly average odour level is predicted to be 0.6 OU/m^3, the peak 1 second odour level is predicted to be 17 x 0.6 = 10.2 OU/m^3 and to occur 3 to 4 times per hour (ie. 10^{-3} probability over 3600 seconds).

For residences 7 km downstream, we would expect the plume to be well-mixed in the vertical plane by the time it reaches this distance. This far field situation then has i_{max} = 0.5 and a peak-to-mean ratio of 3 for P/M60. If the hourly prediction of mean odour level for 7 km downstream is 0.3 OU/m^3, the peak 1 second value is predicted to be 0.9 OU/m^3.

For intermediate distances (e.g. 1 km to 5 km), the situation is between the above near field and far field cases (ie. a mid field consideration). The intensity of fluctuation is likely to vary from 0.5 to 2.3, depending on downwind distance. The peak-to-mean ratio P/M60 will vary from 3 to 17 and this dependence is obviously critical in any evaluation. A screening study is therefore only approximate, so the odour assessment process would need to include the more complex method described in section 10.11.

For example, a receptor at 1.5 km downwind is likely to have i = 1.4, P/M60 around 10 and to experience hourly concentrations of 2.5 OU/m^3 (based on detailed calculations using dispersion models or physical simulations). The peak 1 second odour concentration is then 25 OU/m^3. The results of this example are given in Table 10.2.

Table 10.2. Summary of results, Example 1

	Receptor distance (m)		
Parameter	**500**	**1500**	**7000**
Hourly mean odour level (OU)	0.6	2.5	0.3
i(x)	2.3	1.4	0.5
P/M 60	17	10	3
Peak 1 second odour level (OU)	10.2	25	0.9
Annoyance	Likely	Likely	Unlikely
Odour detection	Yes	Yes	Unlikely

Although the mean concentration gives some guide to the likely zone of influence, it tends to underestimate the effects in the near field and overestimate in the far field. This is also the case when using a constant P/M factor of 10.

Example 2: Piggery, area source

Scenario

A piggery is proposed on a site close to the urban-rural interface. The main odour sources include a moderately sized (50 m x 50 m) anaerobic pond, naturally ventilated piggery buildings, infrequent spraying of excess water onto land within the boundary of the piggery and an incinerator for dead animals. The nearest residences at 1 km distance are worried about the odour impact.

Discussion

This example contains a variety of source types:

- the pond is an area source of a variety of odorous material, with the emission rate likely to depend strongly on wind speed and stability
- building emissions are likely to occur through a variety of vents, along the building sides and in the ridge
- spraying will be a short-lived source of odour
- the incinerator (emissions vented through a short stack) is likely to be an intermittent source, subject to aerodynamic downwash.

The nature of the odour emissions from each source may be quite different.

The receptor distance of 1000 m is likely to make for a mid-field situation.

For the anaerobic pond, we assume the odour emission rate for very stable conditions has been carefully evaluated. We also assume the resulting hourly concentration at 1000 m downstream is a maximum value of 1 OU/m^3 for a wind speed of 0.5 m/s. The receptors are beyond the near field (10 m x 50 m = 500 m downstream) but vertical mixing is unlikely to have been completed by 1000 m downwind. Table 10.1 suggested a P/M60 ratio of between 1.9 and 2.3, giving a peak odour level of 1.9 to 2.3 OU/m^3. For different downwind distances, the procedure can be extended, as shown in Table 10.3.

Table 10.3 Summary of results, Example 2

	Receptor distance (m)		
Parameters	**500**	**1000**	**2000**
Hourly mean odour level (OU)	3	1	0.5
i(x)	0.5	0.45	0.3
P/M60	2.3	2.2	1.9
Peak 1 second odour level (OU)	6.9	2.2	0.95
Odour annoyance	Likely	Unlikely	Unlikely
Odour detection	Yes	Likely	Unlikely

The peak and mean odour level profiles in the region beyond the near field are very similar because of the fairly flat profile of i(x).

For other sources, such as the volume source representing the piggery buildings, we would use a P/M60 of 2.3 for all distances. This is likely to be an overestimate.

For the water spraying, we would expect the odour emissions to last for only a few hours and probably stop by evening if spraying occurs at midday. It would be an intermittent source. Depending on the pattern of spraying, the source would be either a line or an area source.

The incinerator is likely to be a low-volume, high-temperature source, giving rise to maximum concentrations either in low-wind convective conditions or high-wind neutral conditions. If the stack height is 10 m to 20 m, receptors at 1000 m will be in the far field. For low-wind convective conditions, we take $i = 0.5$ and P/M60 = 3. For the high-wind neutral conditions, the plume is likely to be wake-affected, with $i = 0.4$ and P/M60 = 2.3.

Each of these sources is likely to give rise to a different type of odour. Given the infrequent use of the spraying and incineration operations, it is reasonable to consider the odour impacts individually.

Example 3: Metal-plating plant, wake-affected source

Scenario

A typical metal-plating plant has a stack 21 m high. A number of buildings that are 16 m high are located in close proximity to the stack. Two residences are located less than 200 m from the plant and 20 residences are between 200 and 1000 m from the stack. Which peak-to-mean ratios should be applied to this facility to predict near and far field impacts?

Discussion

In the AUSPLUME dispersion model, the building-wake algorithm comes in to play if the plume is less than the building height plus 1.5 times the lesser of the building height or width, within two building heights downwind of the stack. Wind speed and stability class conditions that trigger the building-wake algorithm depend on the stack heights, building dimensions, buoyancy (temperature) and momentum (velocity) plume rise of the particular scenario modelled.

If the peak-to-mean ratio for a wake-affected point source (P/M60 = 2.3) is applied under all conditions, ground-level concentrations are likely to be underestimated for certain meteorological conditions when the building-wake algorithm is not triggered. Similarly, if the peak-to-mean ratios for a surface point source are applied under all conditions (3 to 25), ground-level concentrations are likely to be overestimated when the building-wake algorithm is triggered.

The synthetic meteorological data (described in Table 9.1) can be used with AUSPLUME to determine the wind speed and stability class combinations that would trigger the building-wake algorithm. Additional wind speeds can be added to the meteorological data to more accurately determine the critical wind speed.

Ground-level concentrations of odour (with and without building-wake effects) can be predicted using the synthetic data file and the results compared. Based on this analysis, appropriate near field and far field peak-to-mean ratios can be defined (see Table 10.4). The near field to far field transition point is taken to be 10 times the largest source dimension (10 m x 21 m, approx. 200 m).

Table 10.4 Peak-to-mean ratios used for predicting nose response average ground-level concentrations of odour for a wake-affected small stack

Wind speed categories	Stability class A		B		C		D		E		F	
	NF	FF	NF	FF	NF	FF	NF	FF	NF	FF	NF	FF
<1.2	12	3.5	12	3.5	12	3.5	25	6	25	6	25	6
1.2 – 1.4	12	3.5	12	3.5	12	3.5	25	6	25	6	2.3	2.3
1.4 – 1.5	12	3.5	12	3.5	12	3.5	25	6	2.3	2.3	2.3	2.3
1.5 – 1.6	12	3.5	12	3.5	12	3.5	2.3	2.3	2.3	2.3	2.3	2.3
1.6 – 1.7	12	3.5	12	3.5	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
>1.7	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3

NF near field

FF far field

Two AUSPLUME runs are required to predict nose response time average ground-level concentrations for near and far fields. The variation of emission rate with wind speed and stability class can be incorporated by changing the default wind speed category upper bounds (to 1.2, 1.4, 1.5, 1.6, 1.7 and > 1.7 m/s) and by using the input option for emission rates that vary with wind speed and stability.

10.9 Refined procedure for estimating offensive odour impacts

The screening procedures outlined above will work well for many cases and are easy to use in a dispersion model. They avoid using a single peak-to-mean ratio for all sources types. However, many real situations differ significantly from these generic situations.

In Example 1, including a second similar industry 500 m away would lead to two sources of similar odours operating continuously. For most receptors, being on the centreline of one source will mean being off axis for the other. The near field intensity for the two source configurations is likely to be in the range 2.3 ± 0.3, the mid field intensity 1.6 ± 0.3 (based on numerical modelling measurements). These values are respectively above and below the values for a single elevated point source. If terrain of elevation equal to the typical plume height (200 m to 400 m) is present downwind, plume impacts may be possible in stable conditions, a situation not covered above.

In Example 2, the piggery may consist of two sets of ponds 200 m apart (e.g. a series connection of aerobic and anaerobic lagoons). Their odours may be dissimilar. A receptor 100 m downwind will be in the mid field of both sources and plume overlap is likely to occur for a range of wind directions. These types of source structures are considered further below.

Interpolation scheme for use with AUSPLUME

Formulation

The AUSPLUME model calculates the mean concentration profile C(x,y,z) for a given set of input variables (emission rate, wind speed, direction and stability being of primary importance). The concentration intensity in flat terrain is likely to be a function of effective downwind distance, source size and type and atmospheric stability. Although it would be preferable to set the dependence on C(r) and i(r) on a dimensionless time t/t_L (where $x = Ut$, t_L depends on boundary layer parameters), this is inconsistent with the current AUSPLUME model. Relationships have therefore been sought for i(x,y) for typical wind speeds for a given stability class.

$$i(x) = i_{max} \exp\left(-\frac{1}{2b^2} \{\ln (x / x_{max})\}^2 \right)$$

With the information available, the following centreline profile has been chosen, where:

i_{max} = centreline maximum of i(x)

x_{max} = location of i_{max}

b = constant for given source type and stability classification.

This three parameter log normal distribution has the following suitable properties:

$i(0) = 0$

$i(x_{max}) = i_{max}$

$i(x) \rightarrow i_f$ for $x \approx 10\ x_{max}$.

The last asymptotic relationship is useful for most sources.

Katestone Scientific (1998) tested the distribution for various source types against available wind tunnel simulations, numerical simulations and field data. Although there is considerable uncertainty due to the lack of information, the following important cases have been determined (Table 10.5).

Table 10.5 Initial recommendations for parameters of the log normal distribution for i(x)

Source type/stability	i_{max}	b	i_f	x_{max}
Area/stable, side length L	0.5	0.95	0.25	6L
Surface point/neutral, diameter L	0.9	2	0.4	2L
Line/neutral, length L, across wind	0.8	2	0.5	6L
Elevated point source, convective/neutral				
buoyant	3 to 4	2	1.2	$0.2Z_I$
non buoyant	2 to 3	2	0.8	$0.2Z_I$

Z_I mixing depth

Where there are no recommended values for other stability conditions, the values above can be used.

There is considerable disagreement between field and laboratory values for surface sources.

Having selected i(x), an interpolation scheme is required to determine the peak-to-mean ratio from i(x). For a gamma distribution with a probability of 10^{-3}, a linear relationship holds well for $0.5 < i < 3$:

$P/M = 8.5i - 1$

This ratio is applied to the model's mean concentration prediction to calculate the corresponding peak concentration at the given receptor due to the selected source.

Practical examples using the interpolation scheme

For Example 1, assuming a buoyant source, we assume $Z_i \sim 1000$ m. From Table 10.5, we estimate $i_{max} \approx 4$ at 200 m downwind. The maximum concentration occurs at 300 m to 500 m, where the value of i(x) is still quite large. Similarly, the largest peak concentrations also occur for distances of 300 m to 500 m downstream.

For a non-buoyant source, i(x) has a relatively higher value and the maximum mean concentration occurs at 700 m to 900 m. The highest peak concentrations are expected at 500 m to 700 m.

For the anaerobic pond in Example 2, the mean concentration profile shows a rapid decrease close to the source and a relatively slow decrease for downwind distances over 500 m. The intensity of fluctuations reaches a maximum at 500 m before a fairly strong decline past 1000 m downwind. The corresponding peak-to-mean ratio is similar. The resulting peak concentration shows a maximum value very close to the source and a decline similar to the average concentration.

Caveats

The cited profiles are open to considerable debate and represent a first order description. It is anticipated that any AUSPLUME modifications will allow the user the choice of parameters and provide a set of defaults, together with the option of a constant value for i(x). As it is likely further modifications will be made in future, updated material should be sought before starting any complex evaluation.

10.10 Considerations for practical applications

Applying the process to complex situations (as in many practical applications) is made more difficult by the off-axis variation of peak-to-mean ratios. This is most important for multiple-source evaluations. In addition, many adverse odour situations occur in valleys and nearby valleys, terrain for which there are few generic studies and their applicability may be tenuous.

Fluctuations away from the centreline

Many studies have provided strong evidence for an overall cross wind variation of i(x) for a point source:

$$i\,(x,y) = i(x)\exp\left(\frac{y^2}{4\,s_y^2}\right)$$

where y is the off-axis distance and σ_y is the usual horizontal dispersion parameter. A practical restriction has been made to values of y in the range $\pm\, 3\sigma_y$.

This form of i(x,y) leads to large peak-to-mean ratios off axis although, of course, the mean concentrations at these locations are quite small. For some situations (e.g. elevated receptors) the vertical distribution i(x, y, z) is required. This distribution will depend on the source type and can be quite considerable. There is still a limited amount of suitable information available for most sources.

For practical purposes, estimating peak surface concentrations for a single source need consider no more than the centreline and therefore only relies on i(x).

However, for multiple sources there may often be cases where receptors are not close to the centrelines of plumes from two or more adjacent, independent sources. The form and use of i(x, y) may then become important.

Multiple sources

Assessing multiple sources requires determining the number of hours during which the instantaneous concentration has exceeded a chosen threshold at a given receptor due to the set of sources. This can be caused by any of the sources or, depending on detailed assumptions, by the simultaneous overlap of two or more sources. Dispersion models such as AUSPLUME only evaluate mean concentrations for each source and then sum these for total hourly concentrations. Peak concentrations at a given instance depend more on the source separation and turbulence characteristics (ie. on the degree to which source plumes move in unison or asynchronously). This is a much more difficult problem when calculating concentrations and even more so when dealing with odours.

Many practical odour situations require additional assumptions, given the current state of knowledge. Different types of odour may be additive and for some source types the response could be caused only by the main odour constituent. For widely-separated sources, the odour plumes will move in an uncorrelated fashion and peak values will rarely coincide. In these cases, it may be more practical to consider the peak concentrations individually, by applying peak-to-mean ratios to the mean concentrations due to each single source.

These issues are unresolved. Only interim guidance can be given at this stage. Recommended methods for evaluating multiple odour sources are partially based on assumptions that appear reasonable in the light of the available information.

They are in general agreement with the most recent British, German and American recommendations for estimating stack height for odour control purposes.

The olfactory response to a mixture of odours is not well known but some recent experiments suggest that people respond to the major component only. Therefore, adding mean concentrations for different odour components is unlikely to represent the response to the combined sources.

Even for non-odorous components, it is unclear how to estimate peak concentrations from two or more sources of identical compounds, especially when considering off-axis variations. In general, fluctuations are not additive because of the imperfect correlation between concentration contributions from separate sources. Two separated plumes never fully mix, even in the far field. The degree of overlap (correlation) varies significantly with the ratio of source separation to integral length scale.

The current state of knowledge about multiple source effects is extremely limited and no general conclusions can be made, except that the values of i(x) (and hence P/M) are likely to be reduced compared to a single source.

Two methods are outlined below, one that can be implemented readily from existing dispersion model results and the other requiring change to the AUSPLUME modelling code. Both methods determine whether an odour threshold is exceeded in a given hour due to one or more source types.

Screening method 1 neglects off-axis variations in intensity fluctuations and assumes total addition of contributions from similar sources. If a distance-independent peak-to-mean ratio is used, this simplifies the procedure.

This method can be implemented via the source group option available in AUSPLUME, or by spreadsheet analysis of available dispersion model output files.

Screening method 2 is slightly more complex and requires specially-written adaptations to dispersion modelling code. It incorporates off-axis influences on i(x) and P/M60 and can deal with different assumptions about odour addition.

For similar odour sources, peak concentrations are allowed to be strictly additive for a conservative assessment. For dissimilar odour sources, the exceedance of an odour threshold is separately considered to give a yes/no predicted impact for a given hour. If the degree of source similarity is unclear, these two assumptions should give a suitable range for conservative and optimistic evaluations. In both cases, the initial output of a yes/no odour impact in a given hour can be processed directly to generate odour statistics, or used with other information (e.g. observer attendance and sensitivity) to generate more meaningful odour statistics.

Screening method 1 (conservative)

A moderately simplified procedure is as follows:

1 Separate all the emission sources into groups of similar types, e.g. by odorous compound and source structure.

2 For each source j of strength Q_j^s within the groups, assume:

- there is perfect inter-source correlation
- the centreline peak-to-mean ratios PM_{jk}^s (x) can be defined for the effective downwind distance x
- stability index k can be defined from the recommended values of i(x) and relationships between i(x) and P/M60.

3 For a given receptor, determine the mean hourly concentration C_j due to each source. Evaluate the total peak odour concentration $C_{tot}{}^s$ for a given hour with stability class k:

$$C_{tot}^{s} = \sum_{j e s} PM_{jk} \, C_{j}$$

4 For each source type, determine whether this peak concentration exceeds a selected impact threshold, using suitable annoyance criteria.

5 Repeat steps 2 to 4 for each hour in the meteorological database, flagging whether an odour response is likely.

6 To obtain the total frequency of events with odour annoyance, sum the number of hours when any source type may cause an adverse response.

If the x dependence of PM_{jk} is disregarded, use the following procedure:

1 Multiply each source strength Q by the common peak-to-mean ratio PM_{jk}^s for the source type, to get an effective source strength E_{jk}^s

2 Evaluate the peak concentrations for all sources of type s by substituting E_{jk}^s as the relevant source strength in the dispersion model. In many cases, the dependence of source strength on stability may be ignored. This simplified procedure is very similar to British, German and American recommendations.

3 Evaluate threshold exceedances for each group and every hour of the database.

4 Determine exceedance statistics by evaluating the number of hours when any of the source types gives rise to an exceedance.

The above procedure can be included in AUSPLUME or performed using the ‘save’ files of existing models.

If using the ‘save’ files, the procedure has the added benefit of readily incorporating changes in source strengths and effective exposure times of various receptors (e.g. discounting when an isolated resident is away or asleep).

For Example 2, where major sources are two anaerobic ponds, three piggery buildings and one incinerator stack, the source characteristics would lead to three groups.

The anaerobic ponds have odour strengths Q_1^1 and Q_2^1 and an area source peak-to-mean ratio $PM_k^1(x)$.

The three piggery buildings give rise to odour emission strengths Q_1^2, Q_2^2 and Q_3^2 with a volume source peak-to-mean ratio $PM_k^2(x)$.

The incinerator stack source has a source strength Q_1^3 and, assuming it is unaffected by wakes, a tall stack peak-to-mean ratio $PM_k^3(x)$.

For a given receptor, the corresponding hourly concentrations are predicted to be C_1^1, C_2^1 for the pond sources, C_1^2, C_2^2 and C_3^2 for the building sources and C_1^3 for the stack source. Peak odour concentrations for each type of source are:

- $(C_1^1 + C_2^1)\, PM_k^1(x)$ for the pond sources
- $(C_1^2 + C_2^2 + C_3^2)\, PM_k^2(x)$ for the building sources
- $C_1^3\, PM_k^3(x)$ for the stack source.

If any of these exceed the sensory threshold, then the hour is designated an odour hour.

If the x dependence and stability dependence of the peak-to-mean ratios are ignored, we can use directly-effective emission strengths in the dispersion modelling, as follows:

- E_1^1, E_2^1 for the pond sources where $E_1^1 = Q_1^1\, PM^1$ and $E_2^1 = Q_2^1\, PM^1$.
- E_1^2, E_2^2 and E_3^2 for the building sources where $E_1^2 = Q_1^2\, PM^2$, $E_2^2 = Q_2^2\, PM^2$ and $E_3^2 = Q_3^2\, PM^2$.
- E_1^3 for the stack source where $E_1^3 = Q_1^3\, PM^3$.

Screening method 2 (more complex)

This procedure requires the full use of a modified AUSPLUME model:

1. For a given hour, determine the odour level at a given receptor due to each source Q_j.
2. Determine the off-axis distance y_{jr} and downwind distance x_{jr} of the receptor from each source type (e.g. area, point). From these determine the relevant peak-to-mean ratios $PM_j\,(x_{jr}, y_{jr})$ for the given receptor via the value of i(x,y) and a suitable probability distribution. Determine the mean concentrations $C_j(r)$ at the receptor due to this source.
3. Determine the peak odour level $PM_j\, C_j$ due to each source in the group.
4. To determine the odour response for a given hour:
   a. If the odour characteristics of the sources in group s are similar, calculate the sum of the peak concentrations and compare this with the assumed threshold.

b If the odour characteristics are dissimilar, evaluate the maximum of the individual peak odour levels at a given receptor.

c For intermediate cases, where the sources are similar but spatially well-separated, evaluations 4a and 4b should be performed, giving upper and lower limits for the likely odour level.

5 Generate odour response statistics by considering all source types for all hours and assuming an ‘odour hour’ could be generated by events from any of the source types.

Caveats

The above procedures are likely to fail if:

- sources of different types emit similar components (e.g. hydrogen sulfide from stack and area sources)
- meteorology is substantially influenced by terrain
- sources are either closely-located or well-separated (thus ensuring moderately high or low degrees of coherence).

In such cases and for multiple sources in complex topography in general, further advice should be sought.

Terrain influences

Local topography can have several influences on plume transport and diffusion:

- Upwind terrain can alter the wind flow and turbulence characteristics in the approach flow from that at the nearest meteorological station. Hills or rough terrain can change wind speed and turbulence characteristics and nearby water bodies can considerably dampen turbulence levels.
- Significant valleys can restrict horizontal movement and dispersion and encourage the persistence of drainage flows. Night-time values of horizontal turbulence can be considerably reduced. The terrain may act to select certain eddy sizes and this will influence plume meander and fluctuation statistics.
- Elevated sources may impact on nearby terrain in a very intermittent manner, as the plume is likely to meander fairly chaotically either side of any stagnation point.
- Sloping terrain may act to provide sporadic bursts of turbulent activity within katabatic flows.

Recent wind tunnel investigations for neutral flows and a source elevation 60% of the hill height have found:

- a reduction in plume intermittency on the windward face of the hill
- an increase in vertical meandering and a decrease in i(x) by a factor of 2 downwind of the hill.

These results are difficult to adapt to other sources. It is expected that i(x) for locations downwind of a hill should be reduced and reflect the increase in turbulent intensity (as for wake-affected plumes).

In many situations, where important receptors are located close to waterways at the centre of a valley, the change in pollutant flow from straight-line trajectories may be as important as changes in turbulent structure of the boundary layer.

At this stage no generalised recommendations can be made on the response of i(x) and peak-to-mean ratios to terrain influences. For more complex cases advice should be sought. Evaluations would benefit from collecting site-specific meteorology.

On-site meteorological information

For contentious sites, such as those nearby complex terrain or those close to clusters of residences, it is recommended that a minimum requirement should be to provide one year of 10 m measurements of wind speed, wind direction and horizontal and vertical turbulence. The sampling frequency should be better than 1 hz. An averaging time of no more than 5 minutes is necessary to determine the influence of mesoscale eddies on stable flows. With modern data logging facilities, many ‘turbulence’ characteristics can be computed continuously.

If surface sources are likely to dominate the odour impact, serious consideration should be given to using a two-level (e.g. 10 m and 1 m) tower in order to estimate boundary layer characteristics and near-surface wind speeds, as these can affect dispersion and emission rates.

For complex terrain, consideration should be given to determining streamline deflection and complex drainage flows by the short-term use of a network of three to four single-level anemometer stations. It is likely that flow characteristics can be established from two to three months of monitoring in both winter and summer seasons.

10.11 Where to get dispersion models, other software and guidance documents

Windows-based AUSPLUME version 4.0 can be purchased for $600 by writing to:

Victorian Environment Protection Authority
27 Francis Street
Melbourne 3000.

The BPIP user’s manual and software can be electronically downloaded, free of charge, from the USEPA website: www.epa.gov/ttn/scram

Other dispersion modelling software and guidance documents can be electronically downloaded, free of charge, from the USEPA website: www.epa.gov/ttn/scram/.

10.12 References

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11 Available odour control technologies

Controlling odours is an important consideration for protecting the environment and community amenity. It is possible to detect odours scientifically and measure their impact on the environment. Once this is done there are different methods of control that can be implemented, depending on the source of the odour and various other factors.

11.1 Dispersion

The stack height needed to comply with the glc and/or the odour performance criteria should be determined using appropriate air pollution dispersion modelling.

11.2 Incineration

Incineration is the oxidation of the odorous compounds into (essentially) carbon dioxide and water by combustion with fuel and air. In some cases other compounds may be formed, depending on the mixture of fuel and air used, the flame temperature and the composition of the odour. These compounds could include carbon monoxide, oxides of nitrogen, acid gases and sulfur oxides.

It is important to reduce the moisture content of any gas stream requiring incineration, to reduce fuel consumption.

Afterburners

An afterburner is basically a refractory-lined furnace fitted with one or more burners. The furnace should be fitted with a temperature indicator-controller and an independent high-temperature alarm. Explosion protection systems should be installed if the odorous gas is capable of forming an explosive mixture or if gas is used as the fuel.

The furnace will normally consist of two chambers. These chambers include a mixing section in which the odorous gases are mixed with auxiliary fuel and ignited and a combustion section in which combustion is completed. The gas velocity in the mixing section is normally 8 to 15 m/s to ensure adequate turbulence but reduces to between 6 and 12 m/s in the combustion section. The afterburner temperature should be measured where the gases leave the combustion chamber, with the sensor shielded from furnace radiation.

The critical part of the afterburner is the contact between the odorous gases and the flame and, ideally, all odorous air should be used as primary or secondary combustion air. The efficiency of combustion will decrease with decreasing contact between the odours and the flame.

Catalysts

Catalysts can be used to allow incineration at lower temperatures, allowing fuel savings. However, these unit are susceptible to catalyst poisoning and plugging by solid or viscous particles, making the system ineffective. Designing the afterburner to allow for alternative thermal incineration in such events removes any capital cost advantages of a catalytic incinerator. Proponents of these systems would need to provide clear evidence of successful, extended use in similar applications.

Stack

A stack of adequate height should be installed on the afterburner to ensure proper dispersion of combustion products. A reduction in the efficiency of combustion may arise because of a change in volume or composition of the odorous gas stream. Problems may occur with the burner or fuel supply and this could reduce the combustion efficiency. A tall stack will help disperse any residual odours.

Using boilers as afterburners

A boiler or furnace may be used as an afterburner, provided it is operating at a reasonable load when it is required to act as an afterburner. A liquid or gas-fired boiler, which may be on low fire for considerable periods, is unsatisfactory as an afterburner unless a separate afterburner is installed. Such a system requires a changeover valve, actuated by the boiler, to divert the odorous gas to the afterburner when the boiler is on low fire. Non-condensed gases should be supplied to a boiler as primary burner air.

A coal-fired boiler with a chain-grate stoker is suitable as an afterburner because the odorous gases can be admitted below the grate as under fire air. Such coal-fired boilers normally have high residence times.

Stack

The stack height should be increased, if practicable, when it is known that a boiler will also be used as an afterburner. The additional stack height will improve dispersion and possibly prevent complaints if the odours are not completely incinerated.

11.3 Scrubbing

Liquid scrubbing of gases to remove odours involves either absorption in a suitable solvent or chemical treatment with a suitable reagent.

Scrubbing brings the odorous gas stream into intimate contact with the scrubbing liquid. Unless the odorous substances are readily soluble in the liquid, it is imperative that a large liquid surface is exposed to the gas.

Liquid scrubbing becomes economically attractive, compared with incineration and adsorption on activated carbon, when the volume of odorous gas to be treated is greater than 5000 cubic metres per hour.

Cooling hot gases

It is important that hot, moist streams are cooled before they contact scrubbing solutions. If this is not done the scrubbing solution will be heated and less efficient and the scrubbing medium will be diluted by condensed water vapour.

If a hypochlorite solution is used, there is a chance that chlorine will be lost and the cost of replenishment can be high. There is also a chance that odours will be released from a hot scrubbing solution.

Moisture from the air stream can be condensed using either a direct or indirect condenser:

- In a direct condenser, cooling water is sprayed into the air stream and the cooling water will be contaminated with odorous condensate. If hot, contaminated cooling water is circulated through a cooling tower it is likely that odours will be released to the atmosphere.
- An indirect water-cooled condenser separates the condensed water or condensate for the cooling water. With an indirect condenser, the smelly condensate is segregated from the cooling water and may be discharged to a sewer or water treatment plant. The use of indirect condensers is preferred.

Gas adsorption

The principal types of gas absorption equipment are:

- packed towers
- plate or tray towers
- spray towers
- venturi scrubbers.

If the gases contain hydrogen sulfide, a solution of sodium hydroxide may be used. When the odour is caused by the presence of unsaturated organic compounds, it may be necessary to use an oxidising agent such as chlorine, sodium hypochlorite, potassium permanganate, ozone or hydrogen peroxide. If chlorine, sodium hydroxide, sodium hypochlorite or ozone is used, exhaust gas streams may need to be monitored.

Satisfactory results have been achieved using a sequence of chlorine gas, diluted sulfuric acid and sodium hydroxide to treat odours. The concentration of reagent in the scrubbing solutions must be maintained either by the use of a metering pump or by regular additions of reagent.

Stack

Exit gases should be discharged through a stack, which should be higher than nearby buildings. This will avoid problems with building downwash, which may cause odour complaints, particularly if the scrubbing efficiency decreases. A stack will safeguard against process changes or equipment malfunctions.

Instrumentation

Some additional instrumentation will be needed on the control equipment in order to monitor scrubber pressure drop, liquid flow, pump pressure, temperature and reagent concentration of the scrubbing solution.

11.4 Adsorption

Activated carbon

A method that is suitable for controlling odorous substances, even at low concentrations, is adsorption on to activated carbon. To be effective, the contaminated air stream must be free of substances (such as dust) that might clog the carbon particles. The cost of replacing the carbon can be high, as simple systems use the carbon once only. More complex and expensive systems allow regeneration of the carbon for re-use. Regeneration can produce either a waste water, which will require further treatment before disposal, or a concentrated vapour stream, which can be incinerated more cheaply than the original air stream.

Activated alumina

One proprietary system uses activated alumina impregnated with potassium permanganate. The alumina adsorbs the odorous substances so that the permanganate can oxidise them, usually to carbon dioxide, water, nitrogen and sulfur dioxide, depending on their composition. The alumina bed is replaced progressively as the permanganate is exhausted. This has an advantage over carbon because no further treatment is needed; this may offset the cost of the alumina.

Proponents wanting to use an adsorption system should provide evidence of successful long-term application of the particular process.

11.5 Biofiltration

This method is becoming an acceptable and successful way of reducing odours from biological processes. For odours from process industries, where one or a simple mixture of known chemicals causes the odour, techniques are becoming available to increase the scope of biofiltration.

The procedure is similar to chemical scrubbing, except that in biofiltration the odour is removed by bacterial action. The bacteria grow on inert supports, allowing intimate contact between the odorous gases and the bacteria. The process is self-sustaining. In biological industries (for example, rendering works) it is usual to place the biofilter after the condenser.

Biofilters require careful attention to ensure continued operation. The bed may have to be replaced regularly because of mechanical failure.

Soil-bed filter

In a soil-bed filter the odorous gas stream is allowed to flow through a porous soil with a typical depth of 60 cm. The bacteria in the soil are responsible for the destruction of the odorous compounds. Typical reductions of odour by 99.9 per cent are claimed, with no decrease after a year's operation.

11.6 Masking agents and other odour-control additives

Many products are available for treating or preventing odours in animal facilities, manure storage tanks and lagoons. Most of these products can be classified in one of the following categories:

- **Masking agents**: mixtures of aromatic oils used to cover up an objectionable odour with a more desirable one
- **Counteractants**: aromatic oils that cancel or neutralise an odour so that the intensity of the mixture is less than that of its constituents
- **Digestive deodorants**: contain bacteria or enzymes that eliminate odours through biochemical digestive processes. For example, sarsaponin can be added directly to lagoons, promoting microbial action
- **Adsorbents**: products with a large surface area that may be used to adsorb the odours before they are released to the environment. Sphagnum peat moss, for example, has been found to reduce odour in some lagoons

- **Chemical deodorants**: strong oxidising agents or germicides. Germicides such as orthodichlorobenzene chlorine, formaldehyde and paraformaldehyde alter or eliminate bacterial action responsible for odour production. Oxidising agents such as hydrogen peroxide, potassium permanganate and ozone chemically oxidise odour-causing compounds.

Each of these groups has its strengths and limitations. Masking agents and counteractants, for instance, can be effective for short-term waste storage. However, since these products typically are organic compounds that can be broken down by bacteria, most of them quickly lose their effectiveness in lagoons and tanks.

Digestive deodorants, which contain enzymes, bacteria or both, are advertised for their abilities to break down solids, reduce the release of ammonia and conserve nitrogen. However, no one product affects all of the odour-causing compounds possible in animal manure. Unless the environments of lagoons and other waste-treatment systems are favourable, supplemental bacteria may die off or fail to reach sufficient numbers to control odour. Of the many products tested in The Netherlands and in Germany for their ability to reduce odours from manure slurries, none has proven reliably effective.

Some additives reduce odour by altering the volatility of odorous compounds. Lime, for example, inactivates compounds such as hydrogen sulfide but also increases the amount of ammonia released from manure. Because of an emphasis on reducing ammonia, research in Europe has focused on acidifying agents. Studies indicate that applications of lactic acid bacteria can maintain the pH of manure at 6.4, reducing ammonia emissions by as much as 80% during storage and application. Because this process also retains nitrogen in the waste, there is much more nitrogen applied to land than is the case with lagoon-based systems.

There are a large number of chemicals and proprietary products that may reduce odour when applied to diffuse sources. To reduce odours, these products would have to be applied over very large areas and the cost of materials and labour could be quite high. In addition, the large quantities of compounds required could cause other forms of environmental pollution. However, in certain industries it may be feasible to apply biologically active agents to convert the odours being emitted to less odorous compounds.

While some additives are occasionally effective, it is unlikely that any one product or procedure will eliminate animal odours. More research is needed to establish the usefulness and reliability of products.

11.7 Summary of odour control methods for specific facilities

Operation type	Emissions	Odour control
Boiler	SO_2	A
Acid plant	Acid gases	A, B, E
Fertiliser	Fluorides, fertiliser odour	A, B, F
Rendering works	Decomposing flesh, amines	A, C, D, G
Coffee	Aldehydes, amines	A, C, D
Chicken feathers	Amines	B, D
Fish meal	Amines, aerosols	B, C, D, E
Garbage	Decomposing organics, sulfides	C, G
Ammonia	Ammonia	A, B
Detergent and soap	Soapy	A, B, I

Operation type	Emissions	Odour control
Oil refinery	Hydrocarbons, sulfides (complex)	A,C,G
Chemical plant various	(complex)	A, B, C
Rockwool	Burnt oil, aldehydes	A, B, C
Varnish and paint	Burnt oil, hydrocarbons, aldehydes	A, C
Solvent storage	Various solvents	D, A, G
Animal incineration	Amines, aldehydes	A, C, F, I
Grease trap waste	Amines	B, D, G, I
Fermentation	Yeast, fermenting	A, D, G
Non-ferrous foundry	Burnt core odour, aldehydes	A, C
Ferrous foundry	–	A
Laminated plastic	Phenols, formaldehyde	A, C
Fibreglass	Styrene, acrylates	A, D

A Dispersion. Tall stack is required, moderate capital cost, low running costs.

B Wet scrubbing. Absorption: moderate to high costs, three stages often required. Needs careful selection of scrubber liquor and usually trials. Not always successful, requires regular maintenance and daily tests of active agent and pH control in some cases.

C Afterburner (direct). Temperatures between 600 °C and 1000 °C with residence time of 0.3 to 1 second. Doubling of residence time may enable afterburner temperature to be reduced. Requires careful design to reduce air volume to a minimum. Capital cost high and cost of running is high if air volume large. Needs further control if sulfur or chlorine present in exhaust gases.

Afterburner (catalytic). Temperature 500 °C. Lower temperature operation than direct method but the catalyst may be destroyed if not operated and maintained correctly. This is frequently a problem.

D Carbon adsorption. Needs regenerating at regular intervals. Can be effective but expensive for large volumes. Small operations are reasonably inexpensive to deal with.

E Mist filter. Mist filter of plastic or metal, self cleaning, relatively inexpensive.

F Best management practices. Cleanliness and avoiding spills requires human effort but is relatively inexpensive.

G Masking odour. Deodorant disguises the problem. Usually not effective but can help in marginal cases or with accidental releases and is reatively inexpensive.

H Biological filtration. Has been successful for various industries such as rendering works.

I Condensers. Condensable liquids removed from the exhaust gas stream, reduces the amount of odorous gas to be treated.

11.8 References

Buonicore, A. J. (Ed) et. al., 1992, *Air Pollution Engineering Manual*, Air and Waste Management Association, Van Nostrand Reinhold, New York

NSW Environment Protection Authority, *Environment Protection Manual for Authorised Officers — Odour Control*

South Coast Air Quality Management District (SCAQMD),1995, *Best Available Control Technology Guideline*, Engineering Division

Warren Spring Laboratory, 1990, *Odour Control — A Concise Guide*, Stevenage, UK

12 Sensory properties of odour

An odour is defined as a sensation resulting from the reception of a stimulus by the olfactory sensory system. The sensory perception of odours has four distinct properties: intensity, detectability, character and hedonic tone. The combined effects of these properties are related to the annoyance that may be caused by an odour.

12.1 Intensity

Odour intensity is the strength of the perceived odour sensation. The intensity of an odour is perceived directly without any knowledge of the odour concentration or of the degree of air dilution required to eliminate the odour. Intensity increases as a function of concentration and this dependence may be described as a logarithmic function or a power function. Individual odours have varying degrees of intensity.

12.2 Detectability

The detectability or threshold of an odour is a sensory property that refers to the theoretical minimum concentration that produces an olfactory response or sensation. An odour panel determines this threshold and the numerical values are quoted when 50% of the panel correctly detect the odour. This detection level is defined as 1 odour unit per cubic metre (OU/m^3).

The odour threshold is highly dependent upon the sensitivity of the odour panellists, the method of presenting the odour, the flow rate and the purity of the compound being tested.

The odour **detection** threshold is the minimum concentration required to **perceive the existence** of the stimulus. The odour **recognition** threshold is the minimum concentration required to **identify** the stimulus. The conversion of detection to recognition threshold odour concentration has been shown to vary, depending upon the particular odour.

12.3 Character

Odour character or quality is the property that identifies an odour and differentiates it from another odour of equal intensity. For example, mercaptans are variously described as smelling like rotten cabbage, while hydrogen sulfide is often described as smelling like rotten eggs.

12.4 Hedonic tone

Hedonic tone is a property of an odour that relates to its pleasantness or unpleasantness and should not be confused with acceptability. For example, an otherwise pleasant odour such as perfume may be unacceptable if it is emitted continuously from an industrial site into a residential area, rather than from either a flower garden or perfume worn by another person. Experience and emotional associations largely dictate the degree to which a person may identify an odour as either pleasant or unpleasant. As a result, one person may define odour to be pleasant while many may declare the odour to be highly unpleasant.

12.5 Adaptation

Adaptation or olfactory fatigue may occur when a person experiences a decrease in perceived intensity if the stimulus is received continuously. Sensory recovery is dependent upon the intensity of the odour and generally occurs within a short amount of time after the stimulus is removed. Adaptation to one odour does not generally interfere with the ability to detect other odours. Anosmia is the condition resulting when a person experiences a long-term exposure to an odour and develops a higher threshold tolerance to the odour.

12.6 References

Buonicore, A. J. (Ed) et. al., 1992, *Air Pollution Engineering Manual*, Air and Waste Management Association, Van Nostrand Reinhold, New York

Committee Europe en de Normalisation, 1995, *Odour Concentration Measurement by Dynamic Olfactometry*, CEN/TC264/WG2/N222e, Odours Final WG2 Draft prEN

Standards Australia, 1999, Draft Australian Standard – *Air quality – Determination of odour concentration by dynamic olfactometry*, Project No: EV/007-0600

13 Glossary

A	constant
affected zone	the area within which the glc or odour performance criteria are likely to be exceeded and unacceptable odour impacts may result
AUSPLUME	EPA Victoria regulatory Gaussian dispersion model. (This software should be used for Level 2 and 3 odour impact assessments)
BOD	biochemical oxygen demand
BPIP	Building Profile Input Program (software used to generate data for AUSPLUME to account for building wake effects)
building wake effects	the effect on plume dispersion caused by the presence of buildings near a stack, usually resulting in increased ground level pollutant concentrations
C	convective atmospheric conditions
°C	temperature in degrees Celsius
C_m	mean concentration
C(r)	C(x,y,z) or concentration profile
C_p	peak concentration
diffuse source	activities that are generally dominated by fugitive area or volume source emissions of odour, which can be relatively difficult to control, for example, intensive agricultural activities
dispersion modelling	computer-based software package used to mathematically simulate the effect on plume dispersion under varying atmospheric conditions; used to calculate spatial and temporal fields of concentrations and particle deposition due to emissions from various source types
E	emission rate
EIS	Environmental Impact Statement
EPA	NSW Environment Protection Authority
EP&A	*Environmental Planning and Assessment Act 1979*
EPAV	Environment Protection Authority Victoria
γ	intermittency
$\wp(x)$	probability distribution

g	mass in grams
glc	ground level concentration
glc criteria	glc criteria for individual odorous or toxic compounds specified in mg/m^3 or ppm as a 3-minute average
h	stack height in metres
hz	hertz
i	intensity of concentration fluctuations (total)
i_E	intensity of short time scale fluctuations in emission rates.
i_f	'final' intensity for large downwind distances
i_{max}	maximum intensity
i_p	intensity of plume concentration fluctuations.
i(r)	i(x,y,z) or intensity profiles
K	temperature in degrees Kelvin
kPa	pressure in kilopascals
K	kurtosis
Level 1	a simple 'screening' exercise to identify an appropriate affected zone between odour sources and receptors (and likely future receptors)
Level 2	a screening dispersion modelling procedure
Level 3	a refined dispersion modelling procedure
ln	natural log function
m	length in metres
m^3	volume in cubic metres
m^3/s	flow rate in cubic metres per second
µg	mass in micrograms
mg	mass in milligrams
N	neutral atmospheric conditions
NATA	National Association of Testing Authorities
odour performance criteria	odour performance criteria for complex mixtures of odours specified in OU/m^3 (odour units per cubic metre) as a nose response time average

OU	odour units; concentration of odorous mixtures in odour units. The number of odour units is the concentration of a sample divided by the odour threshold or the number of dilutions required for the sample to reach the threshold. This threshold is the numerical value equivalent to when 50% of a testing panel correctly detect an odour
OU/m^3	odour units per cubic metre
olfactometry	a procedure where a selected and controlled panel of respondents are exposed to precise variations in odour concentrations in a controlled sequence. The results are analysed using standard methods to determine the point at which half the panel can detect the odour
Penalty Notice	Notice issued for breach of specified legislative requirements for which a person may elect to pay the scheduled fine or to have the matter heard by a court.
ppb	concentration in parts per billion
ppm	concentration in parts per million
peak-to-mean ratio	a conversion factor that adjusts mean dispersion model predictions to the peak concentrations perceived by the human nose
P/Mn	ratio of peak concentrations to 'n' minute averages
point source	activities that involve stack emissions of odour; these can generally be relatively easily controlled using waste reduction, waste minimisation and cleaner production principles or conventional emission control equipment
pollution reduction program	A variation to an environmental protection licence aimed at reducing pollution and in accordance with Part 68 of the POEO Act
POEO Act	*Protection of the Environment Operations Act 1997*
Prevention Notice	A notice issued in accordance with Part 4.3 of the POEO Act, aimed at preventing an activity being carried out in an environmentally unsatisfactory manner (as defined in the Act)
SAEPA	South Australia Environment Protection Agency
QA	quality assurance
QC	quality control
QDPI	Queensland Department of Primary Industries
RTA	NSW Roads and Traffic Authority

sensitive receptor	a location where people are likely to work or reside; this may include a residential dwelling, school, hospital, office or public recreational area etc. An odour assessment should also consider the location of known or likely future sensitive receptors
separation distance	the distance between an odour source and sensitive receptors (or likely future sensitive receptors)
σ	standard deviation
σ_c^2	variance
S	skewness
S	stable atmospheric conditions
stack	a vertical pipe used to exhaust pollutants from a process
stationary source	any premises-based activity but does not include motor vehicles
σ_y	horizontal dispersion parameter
t	time period
t_L	characteristic time scale in the atmosphere
U	wind speed
USEPA	United States Environmental Protection Agency
x	downwind distance in metres
x_{max}	distance from source to location experiencing maximum intensity (i_{max})
y	off-axis distance in metres

Z_I mixing depth