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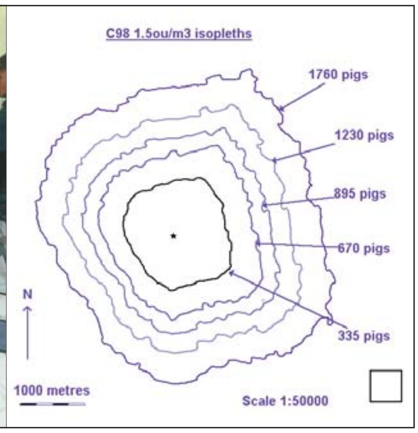
Odour Impacts and Odour Emission Control Measures for Intensive Agriculture

FINAL REPORT



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Management and organisation and consultation

The project was managed by the Environmental Protection Agency. A steering group was formed, with the following members:

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Technical comments were contributed by individuals involved in the Irish pig production sector.

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Contents

Man is the measure of all things

Protagoras, sophist, (c. 485-410 BC)

‘The question whether something is true or false, good or bad, should always be considered in relation to the needs of that person’

Executive Summary

Close to 200 pig units will be applying for IPC licences in Ireland in the next few years, as a result of the EPA Act of 1992 and European IPPC licensing requirements. The assessment of the odour impact of these pig units will be an important element of the licensing process, which will be carried out by the Environmental Protection Agency. Suitable criteria for 'acceptable exposure' to odours are required, in order to set, limit and target values for odour impact. Appropriate odour assessment methods are required to quantify emissions and, if required, to control and enforce licence conditions. To allow pig producers to manage the impact of odours, information is required on the relationship between production practice, housing types and odour emissions, as well as on suitable approaches to the abatement of odour emissions.

This report provides an overview of these issues, based on literature review, a limited programme of measurements and experience gained from the regulatory practices in other countries. This information will assist the EPA in formulating its approach to processing licence applications and in achieving transparent and uniform decision-making on odour issues for that purpose.

This report was prepared by OdourNet UK Ltd. as part of the *Environmental Monitoring R&D sub programme*, supported by an ERDF grant.

Chapter 3 gives an overview of the characteristics of pig production in Ireland. While pig production capacity in Ireland is limited relative to other EU countries, there is a high proportion of large pig units. Approximately 190 units exceed current licensing thresholds and will require an IPC licence. The majority of these (143) are integrated breeding and finishing units. The average size of a pig unit in Ireland is 316 sows/unit, which again is relatively large compared to other EU countries. The density of pigs is relatively low, ranging from 4 to 69 hectares per sow, with an average of 26 hectares per sow. The Irish pig production sector employs approximately 6000 people in pig production, slaughtering, processing, feed production and facilities supply. The investment per sow in an integrated unit ranges between €2,000 and €3,200 and profitability is variable. After a period of generally low prices in 1998 and 1999, leading to losses per pig produced, profitability improved in 2000 due to relatively strong demand and strong sterling. Sixty five percent of production is exported to the UK.

Chapter 4 sets out an introduction to odours as an environmental stressor and provides operational knowledge for professionals involved in odour annoyance licensing and management. The evolutionary origins of our sense of smell, its function and relevance to our social behaviour are explained. The dimensions for characterising odours are identified: detectability, intensity, hedonic tone, odour quality and the recently proposed dimension of odour annoyance potential. In assessing environmental odours, detectability is generally the only dimension used. A European draft standard is in preparation by CEN/TC264/WG2 Odours (EN13725) for measuring odour concentration in European odour units per cubic metre (ou_E/m^3). An odour that is just detectable by 50% of selected panel members is described as having an odour concentration of 1 ou_E/m^3. It must be noted that the relation between perceived intensity and odour concentration is not linear but logarithmic. A useful similarity is that of noise where the linear measure of energy of the noise in Watt/m^2 is translated to intensity using the logarithmic unit dB. Like the odour unit, the dB is based on a sensory detection threshold: at 0 dB 50% of young people can detect a sound at a frequency of 1000 Hz. However, in contrast to common practice for noise, odour concentration is typically expressed in the linear unit (ou_E/m^3) rather than a logarithmic one such as the dB.

The mechanism that leads from the production of pig odours via release and dispersion in the atmosphere to causing odour nuisance in a specific population is complex and is discussed in some detail. Odour nuisance is a result of long-term, intermittent exposure to an environmental stressor, in a complex context of physical, physiological, social and psychological factors that determine the behavioural response of the individual. Odour nuisance is not a linear push-button response to a particular intensity of exposure at any moment by a particular smell. The exposure history is a major factor in the appraisal of the impact of environmental odours. An epidemiological approach is, therefore, the most appropriate tool with which to study the relationship between a source, the dispersion characteristics of a site and the long-term effects on the population in terms of annoyance.

Once that relationship is known, odour impact can be assessed in a more straightforward manner, using source emission measurements combined with dispersion modelling. The results can be assessed using the epidemiological dose-effect relationship, or exposure criteria derived from such a relationship. Assessment of odours is typically undertaken by measurement of emission rates at source, followed by dispersion modelling. Assessment in the field is more difficult, because of the large variations in momentary concentration caused by atmospheric dilution; other background odours (e.g. soil, vegetation) and the practical problems associated with measuring very low odour concentrations ($\leq 20\ ou_E/m^3$).

In Chapter 6 the dose-effect relationship for odour annoyance as a result of long-term intermittent exposure to odours is discussed in detail. For a number of industries in the Netherlands, specific targets for air quality have been defined as a certain 1-hour average odour concentration that should not be surpassed in more than 2% of all hours in an average meteorological year. This criterion, commonly expressed as $C_{98,\ 1\text{-hour}} = x\ ou_E/m^3$, is assessed using a measured source emission and dispersion modelling, using meteorological data for 3 years or more. The target values range from $C_{98,\ 1\text{-hour}} \leq 0.5\ ou_E/m^3$ for rendering plants to $C_{98,\ 1\text{-hour}} \leq 3.5\ ou_E/m^3$ for coffee roasters.

Chapter 7 provides an overview of regulatory approaches taken in a number of countries, including Canada, Germany, the Netherlands, New Zealand, and the United States. Typical setback distances for a relevant number of sows are presented in Table 9 to allow a comparison of the proposed framework with that in other countries.

Recently, a large-scale epidemiological study was conducted in the Netherlands to establish the dose-effect relationship between percentages of population annoyed and calculated odour exposure. The study was carried out for the Ministry of Public Planning and the Environment and used approximately 2,300 standardised telephone questionnaires collected from householders living in the vicinity of pig units.

Chapter 8 sets out a proposed framework of target and limit values based on the results of the Dutch study. This framework provides a starting point for a licensing procedure to be used in Ireland. The proposed structure of target and limit values is:

- **Target value: $C_{98,\ 1\text{-hour}} \leq 1.5\ ou_E/m^3$**
  The target value provides a general level of protection against odour annoyance for the general public, aiming to limit the percentage of people experiencing some form of odour-induced annoyance to 10% or less. The target value is to be used as an environmental quality target for all situations.

  The target value is achieved when the calculated odour exposure for all locations of odour sensitive receptors is less than an hourly average odour concentration of $1.5\ ou_E/m^3$ in 98% of all hours in an average meteorological year.

- **Limit value for new pig production units: $C_{98,\ 1\text{-hour}} \leq 3.0\ ou_E/m^3$**
  The limit value for new pig production units provides a minimum level of protection against odour annoyance, aiming to limit the percentage of those experiencing some form of odour-induced annoyance to 10% or less of the general public, assuming some degree of acceptance of the rural nature of their living environment.

  The limit value for new pig production units is complied with when, for all locations of odour sensitive receptors, the calculated odour exposure is less than an hourly average odour concentration of $3.0\ ou_E/m^3$ in 98% of all hours in an average meteorological year.

- **Limit value for existing pig production units: $C_{98,\ 1\text{-hour}} \leq 6.0\ ou_E/m^3$**
  The limit value for existing pig production units provides a minimum level of protection against odour annoyance, aiming to limit the percentage of people experiencing some form of odour-induced annoyance to 10% or less, in the most tolerant tolerence section

(agricultural/rural) of the population.

The limit value for existing production units is complied with when for all locations of odour sensitive receptors the calculated odour exposure is less than an hourly average odour concentration of 6.0 ou_E/m^3 in 98% of all hours in an average meteorological year.

A phased plan must be made to reduce the odour impact, with time, to the limit value for new pig production units and, eventually, the target value.

These criteria for odour exposure aim to provide a framework that can be used to attain a general environmental quality in Ireland, while recognising that in some cases existing pig production units may need some considerable period of time to achieve that target. In some cases, the time allowed will have to take into account the cycle of normal replacement of assets such as livestock housing, to allow implementation of a structural solution, while avoiding destruction of capital goods.

The implementation of the proposed framework would rely on using emission factors per animal. Specific measurements should not be required, with the possible exception of very large units or production systems that are atypical. A limited programme of measurements was conducted in Ireland for this report, providing indicative emission factors for winter conditions. The results statistically fall within the range of the wider set of annual mean data from the Netherlands. In the absence of a sufficient dataset for Irish conditions, the presented data from the Netherlands provide the best basis for emission estimates for licensing.

A flow diagram for the licensing assessment process for odour annoyance is provided in Chapter 8. It provides a method to decide when to apply a straightforward assessment, using standard contour lines. These standard contours are provided in Annex E and can be used as overlays on a map to estimate the area where exposure is in excess of a limit or target value for odour impact, for a particular number of animals. In more complicated cases, where decisions can become borderline, full modelling is proposed as the preferred assessment method. Detailed information is provided on how to conduct assessments of odour impact for licensing purposes.

Chapter 9 provides an overview of options for reducing odour emissions from pig production. The following options have been identified:

1. *Reduction of odour production*
   a. *Reduction of the protein content in feed*
   b. *Separation of urine and faeces, followed by treatment.*
   c. *Lowering of temperature of stored slurry*
   d. *Collection of slurry in closed tanks, followed by anaerobic digestion.*
2. *Reduction of transfer rate from the surface of slurry*
   a. *pH control*
   b. *Covering the surface*
      i. Natural crusting
      ii. Floating biological covers (straw fibre)
      iii. Floating covers
      iv. Liquid additives (vegetable oils)
      v. Air filled plastic domes (over sludge storage lagoons)
3. *Reduction of exposed area of slurry, including storage, soiled surfaces, grids etc*
   a. *Different housing types*, which include systems such as:
      i. Green Label pig houses, designed for low ammonia emissions
   b. *Frequent removal of slurry and storage in closed tanks*
4. *Extraction of ventilation air with treatment to reduce odour concentration*
   a. *Bioscrubbers*
   b. *Chemical scrubbers*
   c. *Biofilters*
5. *Miscellaneous additives*
   a. *Feed additives*
   b. *Slurry additives*

Generally speaking, low-emission housing systems can achieve a reduction of odour emissions of up to 50%. This approach is best implemented in the course of the normal cycle of replacement of assets. End-of-pipe treatment of ventilation air is generally speaking not an option that is economically feasible. The volume flow of ventilation is large in the relevant season (summer) because it is the main regulating mechanism for temperature and hence is directly related to the welfare and growth of the animals. The odour concentrations are relatively low from the perspective of air treatment systems, with concentrations of a few thousands ou_E/m^3. These factors combine to cause significant additional costs, in the order of €25 per pig produced.

Chapter 9 provides detailed information on odour abatement methods, both process integrated and end-of-pipe methods. Indicative cost information has been included when available in the literature. The economics of installing the technology to abate odour emissions must be assessed before the technology is imposed on existing pig unit operations.

Chapter 10 summarises two case studies that were conducted at pig units in Ireland for this report. In the course of these case studies a limited programme of emission measurements was conducted, with the aim of checking whether the results would fall within the range of values for emission factors found in the recent Dutch study. The measurements in Ireland yielded a geometric mean value of 13.2 ou_E/s per finisher, in winter conditions, which was approximately one third lower than the annual mean of 22.6 ou_E/s per finisher from the Dutch study. A Belgian study found a figure of 15.4 ou_E/s for fatteners in winter conditions, very similar to the Irish emission. However, given the variance observed within and between farms in the Netherlands, the difference is too small to conclude that Irish emissions are systematically lower. To draw that conclusion, a larger programme of odour emission measurements would be required.

Chapter 11 contains the conclusions, which are repeated in this summary:

This report is not answering a well-defined question, with a concise set of conclusions. It aims to provide a framework that will provide a balance between the economic interests of the pig producer and the environmental interests of those using the vicinity in which to live, work and play.

On the basis of the issues explored in this report, a number of general conclusions can be made:

1) A significant number of pig production units will require a licence, based on current National and European legislation.

2) An assessment framework based on quantitative emissions is most likely to achieve a transparent licensing practice that achieves a balance between the interest of the pig producer and those who use the surroundings as their living environment.

3) The proposed assessment framework identifies one environmental target for all situations. To allow for a degree of flexibility two limit values have been set, one for new production unit applications and one for existing facilities. The ‘space’ between the target and the limit values can be used in the licensing process to tailor the conditions to the specific requirements and opportunities that exist for that licence application.

4) The proposed framework for target and limit values is, in general terms, compatible with the setback distances required or advised in other countries, such as Germany, the Netherlands, New Zealand.

5) The prevailing wind direction in Ireland causes a distribution of odours that is not symmetrical. The actual meteorology of the pig unit’s location and the position of the receptor relative to the source are, therefore, a greater factor than in most countries, where the wind rose is more uniform and resultant contours circular. These particular circumstances increase the need for specific modelling, in cases where the outcome is not clear-cut.

6) The geometric mean emission rate of 13.2 ou_E/s per finisher measured in winter conditions in Ireland for this study is about one third lower than the value of 22.6 ou_E/s per finisher found in a larger study in the Netherlands.

7) Given the relatively small number of samples, collected in the Irish study, and the statistical variance as derived from the larger Dutch study, the difference in the mean outcome is too small to be statistically significant.

8) It is, therefore, justified to use the emission factors derived in the Netherlands for emission estimates in Ireland, as long as emission factors specifically measured in Irish conditions are not available for a

larger sample of study sites.

9) Options for reducing odour emissions from pig production exist. Reductions to 50% relative to the most common fully-slatted production unit are quite feasible. However, the financial viability of many retrofit methods is an issue of concern, given the low economic returns on pig production.

10) The economics of installing technology to abate odour emissions must be assessed before this technology can be imposed on existing pig unit operations. The most viable low-emission options involve modification of pig houses, or replacement by new low-emission design housing. In most cases, such structural abatement can only be reasonably achieved in the normal economic cycle of asset replacement.

11) Retro-fitting of abatement, using air treatment systems such as bioscrubbers, chemical scrubbers or biofilters, can achieve significant emission reductions of between 70% and over 95%. The main impediment is the additional cost incurred, which can increase the cost of a pig produced by roughly 10-20%. Market conditions in recent years, generally speaking, do not allow such an increased cost.

12) Good operational practice, including suitable landscaping, tree screens and pro-active community relations, remain a main factor in reducing annoyance and avoiding annoyance developing into nuisance.

13) A suitable production site for a given production capacity will become a major asset for any pig producer and may become a main factor in determining the sustainability of the activity. Producers are well advised to use the planning process to their advantage and be pro-active in counteracting any encroachment into the existing setback zone by developments that may be termed 'odour sensitive receptors'.

14) By making the assessment of the impact in the vicinity of pig production transparent, the proposed framework can contribute in practice to the protection of the interests of both pig producers and the general public.

2. Scope of the study

2.1 Scope

Livestock odours, in particular those caused by pigs, have been a subject of study and of regulation for some considerable time. Guidelines for planning and licensing, aimed at maintaining adequate buffer zones between pig units and residents, have been introduced in some European countries as early as 1971. The nature of pig production has changed since then, while the environmental impacts of pig production have become a major consideration. Nutrient recycling and disposal, ammonia emissions, greenhouse gas emissions and odours are now significant issues determining the sustainability of the industry. The industry has developed various technologies in response to these challenges. New types of pig housing and manure storage have been developed, feed technology is evolving and even air treatment to reduce emissions of ammonia and odour to air is under consideration.

In Ireland, the pig production sector has seen considerable change over the past 12 years. The production of pig meat in Ireland has doubled, while the number of pig producers has been reduced. The trend towards larger units is expected to continue.

IPC licensing for pig production units above a certain size is currently being introduced, on the basis of the EPA Act of 1992 and European requirements.

As a result, close to 200 pig units will be applying for IPC licences in Ireland in the next few years. The assessment of the odour impact of these pig units will be an important element of the licensing process, which will be carried out by the Environmental Protection Agency.

To implement licensing, a transparent framework for assessing the odour impact of livestock production units is required, providing consistent criteria to avoid impairment of amenity in the vicinity of production units. Suitable criteria for ‘acceptable exposure’ to odours are required, in order to set a framework of environmental quality criteria: limit and target values. This report aims to provide the basis for such a framework. It also reviews the practices, methods and technologies that are available to reduce the odour impact of pig production units.

To illustrate the application of concepts outlined in this report, three pilot studies were conducted to illustrate practical implementation of the proposed assessment framework.

This report will assist the Agency in formulating its approach to processing the licence applications and to achieve transparent and uniform decision-making on odour issues for that purpose.

Part A of the report provides the background to the assessment framework, on the basis of literature study and direct contacts with experts and industry representatives.

In Part B two case studies for Irish pig production units are reported, using the methodology and approach as suggested in Part A of the main report. Part B includes a chapter reporting a limited number of measurements that were made to assess whether emissions from pigs in Ireland were within the range of values found in a more extensive survey in the Netherlands. The Dutch data were used to derive emission factors for application in Ireland as proposed in this report.

2.1.1 Study objectives

The study reported here aims to achieve the following objectives:

- Review and evaluate methods for odour impact assessment and prediction.
- Propose criteria and standards to avoid impairment of amenities adjacent to the production unit.
- Identify and review options for reducing odour generation.
- Identify and review odour abatement options suitable for retro-fitting to existing production units

2.1.2 Structure of Part A of the report.

After providing a general overview of the characteristics of the pig production sector in Ireland in Chapter 3, the principles of odour assessment are discussed in Chapters 4 and 5. Aspects of formation of odourants, release to atmosphere, dispersion, exposure and detection, perception and the factors that determine whether an odour becomes an annoyance or a nuisance will be explained. This introduction will provide basic knowledge of the way our human sense of smell works, in the context of environmental odour annoyance. The relationship between perception of odours and health and well-being and the process that can lead from perception of environmental odours to odour annoyance are discussed. The main factors in the process that determine whether annoyance will be an issue will be identified. More detailed background information is provided in annexes.

The dose-effect relationship, between the calculated exposure to odour and the percentage of people 'annoyed' by odours, is discussed in Chapter 6. This relationship is highly relevant, as it provides the underlying data for setting targets for environmental quality, at a level that reflects the needs of a particular society.

An overview of the regulatory approach to pig odours as an environmental issue in other countries is provided in Chapter 7. In Chapter 8 a framework for assessing and managing odour annoyance issues in the licensing process in Ireland is proposed, specifically aimed at the pig production sector. Prevention of odour problems is the guiding principle. The framework provides a systematic approach to achieving a defined minimum air quality target for odour through application of best practice in operation and design, combined with adequate setback distances and possibly specific measures to reduce odour impact to an agreed set of limit and target values.

Chapter 9 describes the causes of formation of odourants. Methods to mitigate odour impact by reducing odourant production are reviewed, including methods for reducing the release of odourants and methods for reducing the impact in other ways, such as using slurry additives or end-of-pipe air treatment, e.g. chemical scrubbers, bioscrubbers, biofilters etc.

In Chapter 10 the results of three case studies are presented. In addition to demonstrating the principles of odour impact assessment as proposed in this report, the results of a limited measurement programme are presented. The measurements, performed at two study sites, were aimed at determining emission factors for finishers, and to compare the results to emission factors derived from a larger study in the Netherlands.

Chapter 11 lists the main conclusions of the report.

At the end of this part A of the report, a number of annexes are included, giving detailed information that is referred to in the main report, followed by the References.

- Annex A *Odour regulations for intensive livestock in other countries* gives details on national regulations, summarised in the main report.

- Annex B *Methods for odour assessment and units of measurement* provides a detailed description of odour assessment methodology, and the units and concepts used to report on odour measurements.

- Annex C *Glossary* contains an extensive list of terms and definitions for odour related concepts.

- Annex D *References* lists the literature references

- Annex E *Contour plots for screening assessment* provides standard contour plots for different pig unit sizes

2.1.3 Conventions

A number between square parentheses indicates a reference to the literature, e.g. [1]. These numbers refer to the list of references, in Annex D *References*. All costs are expressed in Euros (€).

3. Introduction to the characteristics of pig production in Ireland

This chapter provides an overview of the main characteristics of the pig production sector in Ireland. The information provided by the Teagasc Pig Advisory Service has been invaluable in preparing this chapter.

3.1 Overview of the pig production sector and its economics

Pigs are produced to be sold at a profit. That implies that economics determine the dynamics of the pig production sector. The profitability also determines the ability of the pig producers to invest to adapt to market conditions, including environmental requirements, such as odour abatement.

The profitability is largely determined by feed cost and the market price for pork and is subject to significant fluctuations, see Table 1. Since July 1998 the Irish pig sector lost substantial sums. Currently, in 2000, the price for pork is rising again because of short supplies on the increasingly globalised market. Of the meat produced, 65% is exported to the United Kingdom.

The Irish pig production sector employs approximately 6000 people in pig production, slaughtering, processing, feed production and facilities supply.
The investment per integrated sow, in Euro, is between €2000 and €3200.

3.1.1 Distribution, size and type of pig production units

The pig production sector in Ireland includes 657 commercial pig farms, with a total of approximately 175,000 sows. In 1999 they produced 3.8 million fattened pigs. Each sow produces an average of 22.1 pigs in a year. The weight of a fattened pig when slaughtered is typically about 90 kg live weight. An average of 225 kg of feed is required for each pig produced. Approximately 25% of the live weight is removed in the evisceration process during slaughtering, yielding a carcass of 70 kg.

The average size of Irish pig production units is relatively large, at 316 sows/unit (1998), compared to Denmark (103) or the Netherlands (137). Currently there is a trend towards fewer, but larger units. A detailed overview of the size distribution of Irish pig production units is presented in Table 2.

The density of pigs in Ireland, expressed as the number of hectares of farmed land per sow, is relatively low, ranging from 4 to 69 with an average of 26 hectares per sow. Other European countries keep much higher densities of pigs, see Table 3.

Smaller production units currently do not require a licence. When the current licensing threshold is applied (see section 8.2) an estimated total of 191 production units will require a licence, (143 integrated units, 30 breeding units and 18 fattening units)

3.1.2 Strengths of the Irish pig industry

The Irish pig industry has few natural advantages and has managed to survive by being very competitive. Relatively large unit size in comparison with other EU countries means that pig producers are specialists and can employ specialist staff, maintaining a high level of technical expertise. Larger units have economies of

Table 1: Cost, price and profit per kilogram of pig meat produced in Ireland, 1992 to 1999.

Pig production, cost and prices, in Euros per kilogram	1992	1993	1994	1995	1996	1997	1998	1999
Finisher pig price	1.47	1.28	1.28	1.42	1.64	1.43	1.13	1.02
Feed cost	0.97	0.94	0.90	0.86	0.91	0.88	0.81	0.76
Margin over feed cost	0.51	0.34	0.38	0.57	0.72	0.56	0.33	0.27
Estimated non-feed cost for large units	0.39	0.39	0.38	0.41	0.41	0.42	0.42	0.44
Estimated profit / (loss)	0.14	-0.05	0.00	0.17	0.32	0.14	-0.09	-0.18

(Source: Teagasc Pig Advisory Service)

Table 2: Size distribution of Irish pig production units, and numbers of sites to be licensed at current licensing limits.

Integrated breeding and finishing units		
unit size sows	units	Total sows
20 to 49	24	930
50 to 99	48	3450
100 to 299	207	38335
300 to 499	56	21345
500 to 999	61	38720
1000+	26	42585
total	422	145365
To be licensed:	143	102650
Breeding units		
unit size sows	units	Total sows
20 to 49	31	1080
50 to 99	30	2135
100 to 299	40	7180
300 to 499	14	5345
500 to 999	11	6825
1000+	5	6960
total	131	29525
To be licensed:	30	19130
Finishing units		
unit size sows	units	Total no pig finishing places
150 to 499	25	7450
500 to 999	27	18950
1000 to 2999	33	55700
3000 to 4999	11	41400
5000+	7	45500
total	103	169000
To be licensed:	18	142600

(Source: Teagasc Pig Advisory Service)

scale in staff training, purchasing and selling. Smaller units have tended to use selling groups and to a lesser extent purchasing groups to achieve an adequate scale. The progression towards integrated production has also contributed to greater stability in the industry.

Rapid adoption of new technology has been a feature of the industry and explains, for example, the relatively high level of sow productivity in Ireland. The industry has tended to follow developments in Denmark and the Netherlands where innovation has been more rapid than in the UK, which was the traditional model. Widespread use of technical advice combined with performance monitoring and appraisal has contributed to a high level of productivity.

Table 3: Density of pigs EU Countries and regions, 1994 (pigs/km^2 utilised agricultural land).

Country	Average density [pigs/km^2]	Most dense region	Density in the most dense region [pigs/km^2]
Netherlands	724	N.Brabant	2338
Belgium	518	Flanders	1356
Denmark	396	-	-
Germany	139	N.Rhine-Westphalia	367
Spain	61	Catalonia	375
France	49	Brittany	434
Italy	46	Lombardy	256
UK	42	Yorkshire	181
Ireland	32	Cavan	220

(Source: Eurostat, Statistical Yearbook Regions, 1997)

The island location is an aid to the maintenance of the health status of the Irish pig herd. The introduction of liberal EU animal movement policies places a greater responsibility on individual producers, especially breeders. Efficient use of information generated at post-slaughter veterinary inspections is increasingly required to maintain the health of the Irish herd.

The density of pigs in Ireland is relatively low, see Table 3. The contribution of pigs to manure output or nutrient input into agriculture is therefore less than in some other EU countries, where this issue poses a serious restriction to further growth in production (e.g. the Netherlands). In most cases land for manure spreading is available within reasonable distance of pig units. Restrictions on pig production capacity in some other EU regions of high animal density is anticipated, allowing an opportunity for expansion of the sector in Ireland.

3.1.3 Operational characteristics

Most pig production units in Ireland are integrated units, where the entire production cycle takes place in one location. The life cycle of pigs in such a unit is summarised in Table 4.

The housing system of choice is currently fully slatted pig houses, with underfloor slurry storage. The

Table 4: Pig life cycle in an integrated production unit

Pig life cycle	Start	End	Weight start	Weight end	Average growth rate	Optimum temperature range
	day	*day*	*kg*	*kg*	*kg/day*	*Celsius*
Dry sows, gestation	-115	0				19 to 20
Farrowers	0	26				10 to 20
Piglet, birth to 6.5 kg	0	26		6.5	0.3	32 to 34
Weaner, 1st stage, 6.5 - 15kg	27	53	6.5	15	0.3	
Weaner, 2 nd stage, 15 - 35kg	54	89	15	35	0.6	
Finishers, 35 - 93kg	90	175	35	93	0.7	14 to 20

(Source: Teagasc Pig Advisory Service)

European directives on animal welfare will require considerable modifications in the existing housing systems by the end of the year 2005, which may present an opportunity to involve odour emission as one of the selection criteria in selecting suitable housing systems.

The typical production parameters for a typical 100 sow integrated pig production unit are presented in Table 5. The table shows that in an integrated unit, the odour emissions from fatteners are the dominant emission, at 72% of the total. This is compatible with the fact that fatteners consume between 60 and 65% of all feed in an integrated unit.

The emission of the total farm pig population, calculated per sow in a typical integrated unit is approximately 160 ou_E/s . In a breeding unit, the emission per sow is very much lower, at approximately 45 ou_E/s.

The feed used in Ireland is mainly meal and water. This can be delivered to the pigs separately, in a dry feeding system, or pre-mixed in a wet feeding system. Most larger farms use wet feeding. Only a minority of farms use food by-products, e.g. whey, yeast, beer, dough, etc. The feed in Ireland may be different from continental European countries in having a slightly higher protein content. In countries where ammonia emissions and nutrients are a regulatory issue, (e.g. the Netherlands), farmers tend to limit protein content to the minimum. Otherwise, feeding practice in Ireland is similar to that in other European countries.

The differences in operational practice and environment for pig production in Ireland, relative to the Netherlands are outlined below, as these are relevant to explain possible differences in emission factors used in this report. Although the production methods in Ireland and in the Netherlands are bound to differ, the similarities are greater than the differences as far as odour emissions are concerned. The following differences in the

Table 5: Typical characteristics for an integrated pig unit with approximately 100 sows. Number of animals, floor areas and emissions per animal stage.

Typical parameters for approximately 100 sows in an integrated unit							
Stage	Animals	Animals places per sow	Floor area	Area per animal	Emission per animal	Emission per 100 sows and progeny	
	no.		*m^2*	*m^2*	*ou_E/s*	*ou_E/s*	*% of emission*
Sows, farrowing	23	0.22	94	4.09	18	396	3%
Sows, dry	82	0.78	130	1.59	19	1492	9%
Maiden gilts	15	0.14	21	1.40	20	323	2%
Boar	2	0.02	12	6.00	20	43	0%
Weaner stage 1	176	1.68	25	0.14	6	838	5%
Weaner stage 2	240	2.29	84	0.35	6	1371	9%
Finisher	525	5.00	368	0.70	22.5	11300	72%
						15764	100%
						4464	Breeding unit

production practices in Ireland and the Netherlands can be listed:

1. The slaughter weight in Ireland is somewhat lower, which implies lower feed usage per sow per year and lower nutrient emissions.

2. In Ireland the rearing of hogs (boars) for meat is more common than in the Netherlands. Boars are more efficient than castrates, use less feed etc.

3. The mean unit size in Ireland is larger than in Holland.

4. Marginally lower summer temperatures would be expected to require lower ventilation rates, and also result in slightly lower manure store temperatures.

5. The use of wet feeding systems in Ireland is widespread, which reduces dust emissions.

6. Higher nutrient density feeds are used in Ireland, with less manure produced and less fermentable residue in the manure.

7. Raw protein content in the Netherlands is generally lower, to reduce ammonia emissions, which are less of an issue in Ireland.

8. The emission factors in the Netherlands were obtained for partly slatted pig houses, while the fully slatted systems in Ireland are more common. Fully slatted systems will have a higher emission per pig.

Overall, it is not plausible that the impact of these differences is significant. However, only actual measurements on a larger scale can confirm actual specific emission factors for Irish conditions, and their variation from unit to unit.

4. Introduction to odours as an environmental stressor

Summary: This chapter aims to provide a level of operational knowledge that is deemed adequate as general background information for professionals involved in odour annoyance management. The following themes are discussed in this chapter:

- Odour perception: the function of our sense of smell and its evolutionary development;
- Characterising odours: the various attributes used to characterise odours, and the method of measurement;
- The mechanism that leads from the production of odourants from pig production units to odour nuisance complaints

4.1 Odour perception

The chemical senses, for smell (olfaction) and taste (gustation), are generally considered to be the oldest ones in evolutionary development. Although humans are a relatively recent development in evolutionary terms, the function of our sense of smell is the same as for other species: it helps us to evaluate our environment. In simple terms of behaviour, perception of odours can lead to two basic behavioural responses: avoidance or approach. These responses can occur for example in judging food or water, but also in a social or sexual context.

The human sense of smell helps us to assess our environment in a very direct manner. The sensor in the nose cavity is a direct interface between the brain and the environment. It is a highly sophisticated sense, which interacts with our life and behaviour on many levels. The process of odour detection, perception and evaluation is therefore understandably complex. Humans can detect and differentiate up to 3000 odours. Recent research indicates that as many as 1000 genes out of the total of 100,000 in our genome are dedicated to our sense of smell. This significant proportion of 1% suggests that the sense of smell is of considerable importance in evolutionary terms.

The sense of smell is closely related to long-term memory. The nerves that connect the sensor to the brain lead directly to the hippocampus, which is the part of the brain that regulates basic functions, such as the organisation of long-term memory and emotions. It is, therefore, not surprising that smells are often highly associative and can elicit vivid memories of experiences that occurred even in early childhood. This associative aspect is highly relevant to environmental odours. Once a negative association is formed, it is very difficult to change the appreciation of that particular odour stimulus in an individual. This helps to explain why an odour problem from the past often seems to haunt site operators, even after the odour emissions have been significantly reduced.

When an ambient odour is detected by our senses it starts a chain of events. During sensory perception, the detectability, intensity, and character of the odour stimulus are determined. This information is then processed in the brain, in the cognitive appraisal process. At this stage the perception information input is combined with various sources of reference information, such as the history of perception, associative information with previous similar perception events, information on the current visual, social, etc., behavioural status and information about the environmental context etc. If this appraisal leads to a negative appreciation of the perceived odour, in the current behavioural context, the relevance needs to be determined, and the appropriate behaviour needs to be displayed in response. This phase of the process is characterised as ‘coping’. One type of ‘coping’ behaviour involves undertaking actions to remove the cause of the negative appraisal (remove the source). Another type of ‘coping’ is aimed at reducing the emotional impact of the negative appraisal, by ‘reasoning’ that the cause is not so relevant after all and is better ignored. Repeated ‘annoyance events’ as a result of ambient stressors, such as odour, over a considerable period of time, may lead to nuisance, which in turn may result in complaints.

Most odours can cause odour annoyance when they are intermittently clearly detectable. Even odours that are commonly not identified as unpleasant, such as coffee roasting odours, cause odour annoyance in a population that is exposed to sufficiently high concentrations of odours intermittently, but regularly, over prolonged periods.

4.2 Characterising odours: psychophysical dimensions of odour perception

The sensory perception of odourants can be characterised by four major attributes or dimensions:

- detectability;
- intensity;
- hedonic tone;
- odour quality.

A fifth attribute has been proposed recently[1], to characterise the propensity of an odour to cause odour annoyance. However, no operational method for characterisation and interpretation is available for this fifth attribute:

- annoyance potential.

In addition to the sensory dimensions used to describe how odourants act when perceived as odours, efforts are ongoing to devise a more technical approach to characterise odourants, using analysis of the chemicals involved. The approach can be to look at simple key substances that can be perceived as an odour, such as H_2S or ammonia. It may involve measuring a tracer component that is non-odorous itself, but occurs with the odourants, e.g. methane as a tracer for landfill gas. Finally, an attempt can be made to actually measure a multitude of odourants in the mixture, using advanced analytical methods such as GC-MS or 'electronic nose' devices. The practical application of such methods is, so far, limited. The sensitivity of the analytical methods is usually not nearly sufficient to approach that of the human nose, and the poor capability to predict or model the actual odour perception in humans on the basis of measured parameters is poor.

The different dimensions used for characterising odours, the methods for assessment of odour samples and the units used to report measurement results are described in some detail in chapter Annex B of this report, titled *Methods for odour assessment and units of measurement.*

4.2.1 The common traits of units used for odour and noise assessment

Our senses are equipped to respond to a wide range of stimuli. Our ears detect faint sounds, but can also cope with very loud noises: from a whisper to a roar. We can pick out a specific conversation in a room full of loud conversation. The response characteristics of our sense of smell are similar. It is, therefore, helpful to consider the way in which we describe environmental noise, and identify the relevant similarities with units used to characterise odours.

The stimulus for noise is vibration of the air. The energy of that vibration determines the strength of the stimulus. This energy is measured in linear units, Watts per square metre, (W/m^2). The energy that is picked up by the human ear is an even smaller quantity. Our eardrum is only 1 cm^2, or 10-4 m^2. Our ear, therefore, can perceive an energy level of 10^{-16} W, which is very little.

The loudest noise that we can perceive is close to the pain limit, where hearing turns to hurting. The stimulus there is 10 W/m^2, or an energy uptake of 10^{-3} W by our eardrum.

As powers of ten are not the most intuitive of measures, we use logarithmic measures to describe these stimuli, where the number of zeros, or the powers of ten, are more important than the difference between two numbers like 3000 and 5000, for example.

The idea to describe a signal, or stimulus, in terms of a logarithm of the proportion (or ratio) between the actual value and the detection threshold, is attributed to Alexander Graham Bell (1847-1922), the inventor of the telephone. He was interested in describing the strength of signals, and coined the unit: bel.

In mathematical terms:

$$L = \log(I/I_0)$$

where I is the strength of the signal, and I_0 is the smallest detectable signal. As this measure is a bit crude, the decibel is more common:

$$L = 10 \cdot \log(I/I_0)$$

The decibel is best known for describing noise levels. In noise levels, the reference value I_0 is the detection threshold for a sound of 1000 Hz frequency, established experimentally, in sensory experiments using young people as panel members.

Therefore, $I_0 = 10^{-12}$ W/m^2 at 1000 Hz, and a stimulus of 10^{-12} W/m^2 $\equiv$ 0 dB.

The same model can be applied to odour intensity[2]. In the European standard EN13725 the threshold value, or zero odour decibel is defined as equivalent to an odour of 40 ppb n-butanol. The choice of a particular odour is not dissimilar to defining a particular frequency for noise.

So, if 0 $dB_{od} \equiv$ 40 ppb n-butanol = 1 ou_E/m^3, then odours can be expressed, just like noise, in decibels; dB_{od}.

For the reference odour, the mathematics work very well. The stimulus of 4000 ppb = 4 ppm n-butanol can be described as:

$$L = 10 \cdot \log(4000/40) = 10 \cdot \log(10^2) = 20\ dB_{OD}$$

For other odours, the reference may be different. For sound a number of different reference levels are used, hence the variety in decibels: dB(A), dB(B) and dB(C), all with a slightly different reference value, each defined as a spectrum of a defined set of frequencies.

So, the strength, or intensity of both noise and smell can be defined on the basis of a detection threshold for a particular stimulus in people.

The anchor for the odour unit is the detection threshold, which has been defined using 40 ppb of reference odourant n-butanol, based on tests with human subjects. This detection threshold is described by 1 ou_E/m^3 which is equivalent to 0 dB_{od}.

The anchor for noise is the detection threshold for a sound of 1000Hz in W/m^2, experimentally determined to be approximately 10^{-12} W/m^2 in young people.

A sound at the upper end of the sensory range of hearing (extremely loud) is 130 dB. In linear terms, the energy of that sound is 10,000,000,000,000 times the detection threshold, in linear units of W/m^2.

For odour, the range between detection thresholds and unbearably strong smells is smaller, but still considerable. Odours at the high end of the intensity range (extremely strong) may contain hundreds of thousands or even millions of ou_E/m^3. Therefore the range of odour intensities, in dB_{od}, is open ended, but relevant in the range of 0 to 60.

Although the dB_{od} has been proposed some time ago[2], and is also included in the draft standard EN13725, it is not commonly used. When interpreting odour measurements it is, however, useful to realise that the odour concentration, ou_E/m^3 is a linear unit, just like W/m^2 for noise. The principal similarity between these units is that their relation to perceived intensity cannot easily be interpreted intuitively. These linear parameters tend to reach very large values, making clumsy numbers in practical use.

By using dB units, similar to noise, odour intensity can be associated with a more tangible unit, directly comparable to the decibel used in noise assessment. For example, a reduction in odour concentration by a filter with 90% efficiency amounts to a reduction with 10 dB_{od} while a filter performing at 99% abatement efficiency achieves a 20 dB_{od} reduction in odour intensity.

4.3 The mechanism leading from pig smell to odour nuisance

Pig producers have a responsibility to minimise the impact of their activity in the vicinity of their production site. They have a legal obligation to avoid impairment of amenities. Odours are probably the predominant nuisance issue for pig producers, with the potential to reach well beyond the limits of the production site.

Odour nuisance can develop after long-term intermittent exposure to odours that cause a negative appraisal in the individual concerned. It has to do directly with the way we value our environment. It is not a straightforward process. Our attitudes towards the source, the inevitability of the exposure and the aesthetic expectations regarding our residential environment are some of the less tangible factors that are relevant to the probability of experiencing nuisance. Once the balance tips, and an environmental stressor, such as a livestock odour, becomes a nuisance to an individual, it is very difficult to reverse the process. What used to be a faint odour has now become a stimulus associated with annoyance. Once the first complaint has been made, the problem becomes much more serious than before for all those affected.

The mechanism that leads from an emission of odourants to the atmosphere to actual odour nuisance is quite complex. It involves the following main factors:

- The characteristics of the odour that is released (detectability, intensity, hedonic tone, annoyance potential);
- Variable dilution in the atmosphere through turbulent dispersion (turbulence or stability of the boundary layer, wind direction, wind speed, etc.);
- Exposure of the receptors in the population (location of residence, movement of people, time spent outdoors, etc.);
- Context of perception (i.e. other odours, background of odours, activity and state of mind within the perception context);
- Receptor characteristics (exposure history, association with risks, activity during exposure episodes, psychological factors such as coping behaviour, perceived health and perceived threats to health).

This process can be summarised as:

formation of odourants → transfer to atmosphere → atmospheric dispersion → exposure → population → perception → appraisal → annoyance → nuisance → complaints

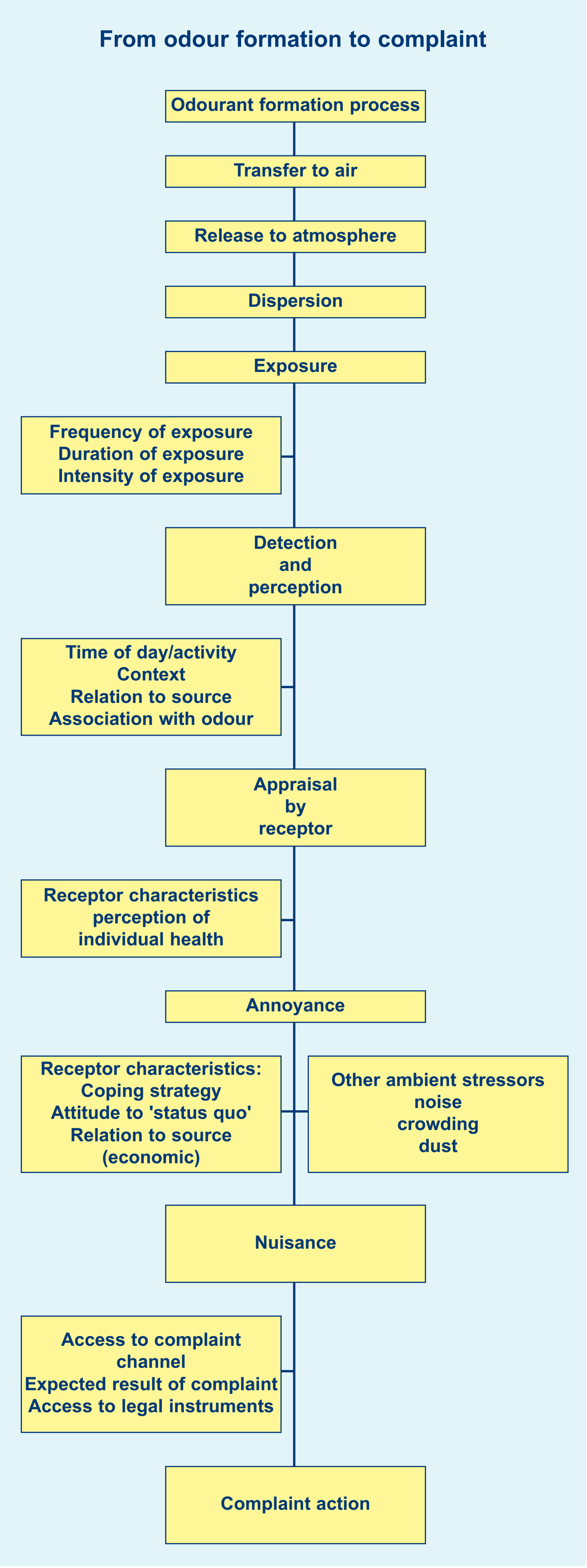


Figure 1: Pathway of odour from production to receptor

When we look at the underlying mechanisms, the factors that play a role are more diverse and mutually interactive, as is illustrated in Figure 1.

For practical purposes, such as regulatory use, the complex relationship between nuisance (effect) and exposure to odours (dose) can be described in a simplified model that does not take into account all these different factors. The dose-effect model linking 'exposure to odours' to 'nuisance' is typically described as the relation between modelled exposure and annoyance as measured by a standardised telephone questionnaire or, alternatively, complaint records. Epidemiological methods are used to describe this relationship.

The exposure is typically quantified in terms of a frequency of occurrence of hourly average concentrations above a certain limit odour concentration, e.g. 5 odour units per metre cubed (ou_E/m^3) as a 98-percentile of hourly averages of odour concentration for a year with average meteorology. In short notation: $C_{98,\ 1\text{-hour}} = 5\ ou_E/m^3$. This measure of exposure is calculated from an estimated or measured odour emission from the source, using an atmospheric dispersion model.

Air quality criteria for odour can be set on the basis of combining calculated exposure with knowledge of the dose response relationship to quantify and assess odour impact. However, this relationship will not be the same for every community. It is determined by factors such as crowding, expectations of environmental quality, economic priorities, etc. Although odour can have direct effects on well-being, and hence on health, it is to some degree an aesthetic factor in environmental quality.

To set environmental exposure criteria with a view to avoiding odour nuisance is, therefore, not only a scientific, but also a political process. The range of political discretion is limited, however. Unlike other air pollutants, every citizen with a functioning nose can assess odour real-time. The appraisal is immediate and the outcome is readily communicated to the relevant authority in the form of complaints.

5. Impact assessment methodology

This section describes different methods for assessing odour impact. Some of these methods start with the effect, by primarily studying the people involved and their behaviour. This same perspective can be used experimentally, using trained field panels for conducting field observations, either for a short period of time or for a period of many months.

The most common method for impact assessment, however, is to use knowledge of the dose-effect relationship between odour exposure and annoyance to predict annoyance levels on the basis of calculated exposure. The starting point for calculated exposure is measurement of odour emissions at the source.

Measuring odour concentrations 'at the site boundary' is not an effective method, even though it would fit well with the legal approach to nuisance. The variability that is introduced by weather conditions and the practical difficulty of measuring odours at very low concentrations, $\leq 20\ ou_E/m^3$, are so far insurmountable methodological obstacles for measuring an interpreting 'ambient odour concentrations'.

5.1 Assessment of effects

5.1.1 Direct measurement of percentage of people annoyed

The Standardised Telephone Questionnaire (STQ, also known by the acronym: TLO) is used to measure the percentage of people annoyed in a sample of the population[3]. The main application is to determine dose-effect relationships, either in general or for a particular site.

The TLO is typically applied to sufficiently large samples of the exposed population, in at least four study areas, with different exposure levels. By collecting at least 100, preferably 200, TLO results for each exposure test area, a dose-effect relationship can be established.

There is no standard document with a protocol for this technique, although a unity of application exists in practice in the Netherlands, where the method has been applied relatively widely[3]. A specific large scale dose-effect study for pig production odours has been carried out there recently[4], and is an important contribution to the data underlying this report (see also section 6.2). The method requires specialised expertise. Specialised odour survey firms with suitable experience are required to apply the methodology successfully.

The cost of such a survey is in the order of €15,000, for one site. Its application in specific licensing cases is limited, as in most cases the number of people exposed is insufficient to apply the method successfully. Direct measurement of annoyance is a valuable method to determine the underlying dose-effect relationships, in carefully selected case studies.

5.1.2 Complaints analysis

Complaint analysis is not covered by any standard method or recognised protocol. Usually complaints are registered by local, regional or even national authorities or by companies who have a customer relations system that can be adapted for complaint registration.

Complaints registration provides an insight into the prevalence of a symptom of odour annoyance, but not of the prevalence of the annoyance itself. There are many factors at play that determine the ease or difficulty of registering a complaint. Therefore, complaint data must be interpreted with some caution. Registered complaints are a very strong indication that odour nuisance is a reality in a specific situation. However, the absence of registered complaints does not necessarily indicate the absence of nuisance. Also, once a conflict situation develops over odour emissions, the registering of complaints can become a tool in the fight, when residents use orchestrated complaints as a political lever to move the argument in their favour.

The approach in setting up complaints registration and analysis must be determined and tailored to the purpose of the registration.

The minimum information that needs to be collected for each complaint is:

- Location where the offensive odour occurred, within approximately 100m. (i.e. address complete with house number);
- Date and time when the offensive odour was observed;
- Characterisation of offensive odour, preferably on the basis of a choice from standardised descriptors;
- Preferably the identity of the complainant, to assess repeated nature of complaints;
- Residential address of complainant.

In complaint analysis each complaint should be verified and collated with additional information:

- Wind direction, wind speed and stability class at the time of complaint;
- Any process incidents at the time of complaint.

The benefits of a complaints registration system can be greatly improved by implementing a standard protocol for complaint data registration and processing. Professional advice, including co-ordination with complaint registration units of the local authority or other organisations, is advisable.

A quick and adequate response to complainants is vital in those situations where community relations can be improved. This part of the complaints response process should be regarded as a fully-fledged method of annoyance reduction, as it can be very beneficial indeed to reduce anxiety in the complainant by adequate response and supply of information.

The results of complaint registration and response should be fully analysed periodically.

5.2 Direct assessment of odour exposure

5.2.1 Direct field methods

5.2.1.1 Field panels, short-term evaluations

Field panel measurements provide an estimate of total emissions from a source, including all diffuse sources.

Field panels consist of 4 to 6 trained, qualified panel members selected using the same criteria as used for the odour laboratory, according to prEN13725. The field panel makes observations on locations in the field, usually to determine the maximum distance of detectability of the odour from a particular source. This result, combined with the meteorological conditions during the field observations, is used for 'reverse dispersion modelling', which gives an estimated source emission rate as a result. Field panels can also be used to provide information on odour intensity and/or hedonic tone in field conditions.

A practical test procedure is described here. At any given location the panel makes observations every 10 seconds, for a duration of up to ten minutes. By traversing the 'plume' at intersections at varying distances, the results are gathered in the course of a number of hours[35]. The technique has been applied for a number of years, in some countries, in applied odour research. An unofficial guideline for carrying out these measurements has been published in the Netherlands[6], while in Germany a guideline has also been published: VDI3940:1993[7].

Field panels can not only be used for evaluating detectability of the source as a whole but also as a more 'analytical' instrument by teaching the panel to identify specific smells on-site and using this perceptive expertise to identify individual sources downwind. Using this technique the following information is recorded: type of smell, intensity and relative annoyance potential to the overall off-site smell. This provides useful qualitative data, although they cannot lead to decisive conclusions as they reflect an assessment by a limited sample of the population, only briefly exposed to these odours.

The field panel work requires certain weather conditions and characterisation of meteorological conditions during measurements (wind speed, wind direction and stability class)

The inherent uncertainty of the method of measurement is mainly determined by the inaccuracies involved in characterising the turbulence in the mixing layer of the atmosphere, and the relatively poor capabilities of models to accurately predict short-term downwind concentrations. Generally speaking, the results of modelling impact on the basis of source emission data will give a more reliable result. Field panel data can, however, be invaluable in providing a field check based on actual conditions, especially where sources are complex and include diffuse sources (i.e. natural ventilation, large area sources etc).

5.2.1.2 Field panels, long-term evaluations

In 1994 an odour regulation for industrial sources on the basis of long-term field observations was introduced in the state of Nordrheinland-Westfalen: Geruchs Immissions Richtlinie (GIRL)[8]. This guideline is based on measuring the actual frequency at which odours can be perceived in the vicinity of the source in question, over a period of 6 to 12 months.

A number of fixed observation points are determined, on a regular grid, access allowing. A number of observers are assigned to the task of making observations at these points, according to a pre-determined schedule. The assessor makes observations at 10-second intervals, over a 10-minute period. The number of observations with a positive detection is divided by the total number of observations in the 10-minute period, and a percentage of positive observation is calculated. If the percentage is above a limit value, typically 10%, the measurement at that point in that 10-minute interval is considered to be an ‘odour hour’. The frequency of ‘odour hours’ is used as the criterion to determine if a ‘relevant nuisance’ exists at that grid point. The limit value that is applied in Germany for residential areas is 10%, while for trade and industrial zones a more lenient 15% limit is applied.

The method requires approximately 26 measurements, on different days, for each point, while allowing no more than 5 of these measurements to be done by the same assessor. The requirements for human resources are therefore considerable.
The methodology is described in the guideline VDI3940:1993 and in the GIRL[8].

The method has been applied to a pig fattening unit of 1760 fatteners. It was found that the criteria were not met at distances of up to 1000 m from the pig unit[9].

The long-term field panel method is useful, in that its methodology and approach are easily envisaged, and understandable. The considerable resources and cost involved are limiting factors in its practical application. Concerns have been raised about the statistical basis of the experimental design, when the assessment programme is in any way limited because of practical and/or cost implications.

5.3 Assessment of odour impact by measuring emissions at source, followed by dispersion modelling

This section describes the practical methods used to assess odour emissions at source. The need for carrying out such measurements for actual licensing purposes will be limited, as reliable emission factors for odour emissions for pigs at various stages of their life cycle are available[10]. These emission factors were obtained using the methods described in this section.

If emission factors are available, sampling can be avoided, and estimated emissions can then be used as input for atmospheric dispersion modelling, as described in section 5.3.3.

5.3.1 Sampling

When sampling odours, appropriate Health & Safety procedures must be applied. The Source Testing Association (UK) has drafted specific guidelines for environmental sampling.

Sampling must be carried out in accordance with the CEN standard prEN13725 [11]. Samples are collected in odour sampling bags made from a suitably odour free material, such as Nalophane. Odour samples must be analysed as quickly as possible, but no later than 30 hours after sample collection.

5.3.1.1 Point sources

Point sources must be sampled in accordance with the CEN standard prEN13725 [11].

If a risk of condensation of the odour sample in the bag exists or when concentrations are expected to be higher than the measuring range of the olfactometer to be used, dynamic pre-dilution on site may be required.

5.3.1.2 Area sources

Area sources must be sampled in accordance with the general principles of CEN standard prEN13725 [11].
To establish specific emission rates from liquid or sludge surfaces a sampling hood is the preferred method.

In using the sampling hood method, the choice of the correct parameters of operation is of vital importance. The sampling hood must use a flow velocity under the hood of 0.2-0.3 m/s and have a headspace height of no more than 200 mm. The path length must be sufficient to allow the concentration under the hood to reach values that can be readily measured using olfactometry.

Generally speaking olfactometry becomes more difficult at concentrations below 50 ou_E/m^3 because of background odours in sample bags etc.

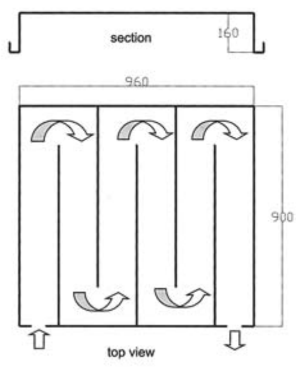


Figure 2: Example of Lindvall sampling hood for area sources

As an example a Lindvall-type sampling hood of suitable dimensions is pictured in Figure 2. The section of the headspace is 160 x 160 mm with a total path length of 6 x 960 = 5760mm. The 'hood constant' *L* can be calculated as:

$$L = \frac{\text{flow path section } [m^2]}{\text{covered area } [m^2]}$$

Once the hood factor *L* is known, the specific emission rate can be calculated from the concentration measured at the exit of the hood and the flow velocity *V*:

$$E_{sp} = C_{hood} \times L \times V$$

In our example the hood factor *L* is 0.006944, and the flow velocity *V* = 0.25 m/s, which implies that at a specific emission rate of 1 $ou_E/m^2/s$, an odour concentration of 144 ou_E/m^3 is measured at the exit of the hood.

This implies that emission rates as low as approximately 0.5 $ou_E/m^2/s$ can be measured without coming too close to the lower detection limit of the method of the odour concentration measurement (approximately 50 ou_E/m^3).

5.3.2 Odour concentration analysis

Odour samples must be analysed in compliance with the draft standard EN13725 'Odour concentration measurement by dynamic olfactometry', see Annex B.1. for details.

5.3.3 Modelling of atmospheric dispersion

Once the odour emission rate from the source is known (in ou_E/s) the impact in the vicinity can be estimated. The impact of an emission is very strongly determined by the way in which the odour is diluted in the atmosphere, while being carried towards the receptor by the wind. The dilution can vary considerably, depending on the meteorological conditions: wind speed and turbulence of the atmosphere, also called atmospheric stability. The meteorology of a site will be a major factor in determining the impact of a certain release of odours. To predict the impact as well as we can, computerised mathematical models for atmospheric dispersion models are used.

5.3.3.1 Characteristics of suitable atmospheric dispersion models

Dispersion models are used for predicting odour exposure with a view to assessing expected annoyance. The relationship between odour exposure and annoyance has been established in a number of epidemiological studies, where a particular modelling approach was used. *When using dispersion models for odour annoyance prediction, the objective must be to apply the models that were used to establish dose-effect relationships in the underlying epidemiological case studies.* This implies that, although better atmospheric dispersion models may become available, these can only be applied to odour problems *after* their results have been validated in dose-effect studies, or by using base data from previous dose-effect studies.

The relationship between modelled odour exposure and actual annoyance levels has been established using models and data with the following characteristics:

- Gaussian plume models were used;
- to represent conditions for an 'average year' hourly meteorological data for a period of at least 3, preferably 5 years were used;
- models were used to calculate one-hour average concentrations for all hours in the meteorological dataset;
- exposure was expressed as the concentration corresponding to a certain percentile of the distribution of hourly values, usually the 98-percentile.

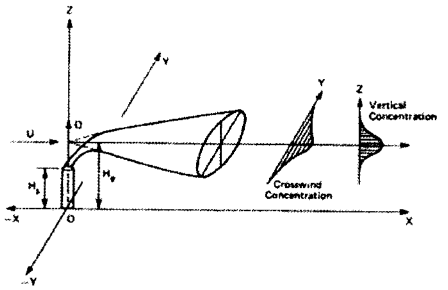
A commonly used model is the Industrial Source Complex (ISC) model developed by the US Environmental Protection Agency and used as a regulatory tool for atmospheric emissions in many parts of the world. ISC is a Gaussian dispersion model, which uses input data such as wind speed, wind direction, atmospheric stability and height of the mixing layer to determine ground-level concentrations at defined receptor points.

In establishing odour exposure with a view to assessing the risk of odour annoyance, similar models must be used. Models that produce results that do not closely resemble those commonly applied to odour problems *must be validated for that application* before they can be used.

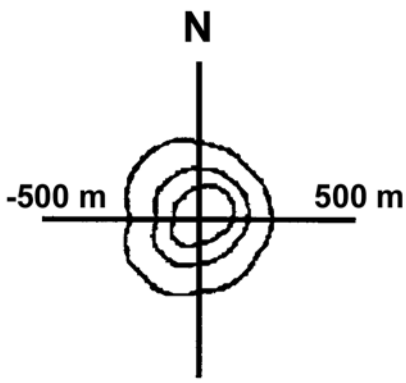
For practical purposes, other Gaussian models that are able to predict the frequency of 1-hour average

Atmospheric dispersion models

Most dispersion models are Gaussian models, which assume the concentration profile across the plume to follow a Gaussian probability curve.



The expansion of the plume is modelled by mathematically representing the standard deviation as a function of distance to source, wind speed, and atmospheric stability (turbulence). By repeated calculation of each receptor point in the study area, for each hour of the weather data set, a frequency distribution of hourly concentrations at that receptor point can be obtained. This distribution can be characterised by the concentration that is exceeded only 2% of time, in terms of hourly average concentrations. This is commonly called the 98-percentile. By drawing a line on the map connecting all points with the same concentration at the 98-percentile, for example at 5 $ou_E \cdot m^{-3}$, an odour contour line can be shown on a map. In the area enclosed by the contour the exposure level 5 $ou_E \cdot m^{-3}$ as a 98 percentile of hourly averages will be exceeded. Outside the contour the exposure will be less than the given criterion.



concentrations can be used.

The results are presented as contour lines for specific frequencies of occurrence of odour concentration with hourly average values above a certain limit value (air quality criterion).

In this report, the COMPLEX atmospheric dispersion model[26,27] was used to calculate overlay contours. This US-EPA model, that is based on the widely used MPTER and ISC models, has been adapted by OdourNet to accommodate numerous sources (up to 999 sources) and to provide high percentile values (e.g. 95, 98 or 99.5 percentiles of 1-hour average calculated concentration) that are used to evaluate odour impacts. Odours, by the nature of our olfactory sense, which responds almost immediately to a stimulus, has a very much shorter time frame to cause effects in receptors than most other common forms of air pollution. However, dispersion models are not typically designed nor validated to be used at averaging periods shorter than 1 hour (see also section 5.3.5).

For the standard overlay contours, the hourly meteorological data for Claremorris meteorological station were used, for the years 1993-1995 (inclusive).

5.3.4 On the choice of meteorological data

For modelling purposes suitable meteorological data are required, consisting of 8760 hourly observations per year for the following parameters:

1) Wind speed

2) Wind direction

3) Atmospheric stability, which can be:

   a) Pasquill stability class (derived from cloud cover observation)

   b) Monin-Obukov length (derived from measurement of incoming solar energy)

To avoid error because of year-to-year variations, a minimum of 3 years continuous hourly data are required, while a 5-year period is considered preferable.

Data should be obtained for the 'most representative' meteorological station. This may not always be the closest station, especially where the issue of coastal versus inland locations is concerned. Specialist advice can be obtained from the Met Office.

Meteorological data from individual stations are available from a number of suppliers (e.g. the Met Office or Trinity Consultants in Austin, Texas), at a budget cost of approximately €1200 for 3-5 years data from a station. The data has to be formatted so that they are suitable for use by the software of the dispersion model.

For Ireland, data are available for the following meteorological stations, typically for the period 1993-1998, and in many instances going back to 1990 or earlier:

- Belmullet Peninsula
- Casement
- Claremorris
- Connaught Airport - 1997 and later only
- Cork Airport/Corcaigh
- Dublin Airport
- Kilkenny
- Malin Head
- Rosslare/Ros Lair
- Shannon Airport
- Valentia Observatory

It must be noted that most of these stations are coastal stations that are not suitable for characterisation of more inland locations, even when the distance to the coastal station may be less than the distance to an inland station. Also, data from some stations are not continuously registered and are therefore not suitable for dispersion modelling for odour impact assessments.

A more in-depth comparative analysis of differences between the dispersion patters of different meteorological stations with a view to odour impact assessment would be advisable in the course of formulating a regulatory odour guideline.

5.3.5 On the choice of percentile values

In setting exposure criteria different percentiles can be used. However, these percentiles all reflect one distribution of values, determined by the meteorology at the location in question. Therefore, there is a relationship between a certain limit value at the 98-percentile, at the 99-percentile and at the 99.5-percentile.

In choosing a suitable percentile to reflect a certain exposure level, both fundamental and practical issues must be considered. A fundamental issue is that for characterising the exposure conditions that determine odour induced annoyance, the relatively rare hours with high exposure are more determining than the majority of hours when the exposure is average or below average. This is a result of the exponential relationship between concentration and perceived intensity (see section in Annex B.2) and the psychophysical and psychological processes involved. A practical issue is that the uncertainty of the prediction of the model is becoming greater at very high percentiles. The mean of the distribution has a smaller margin of error than the 'tails' of the distribution. At the high end of the percentiles, the outcome becomes increasingly vulnerable to the small fraction of hourly meteorological observations that are of questionable quality, because of instrument failure, missing values etc. The 99.5-percentile, after all, is determined by only 44 hourly observations in a year.

In this report, the 98-percentile is used to set criteria, because this value can be seen as a compromise: it reflects the upper 'tail' of the distribution, but is based on the top 175 hourly observations in a year. To make this value more representative, a minimum of three years meteorological data is used, or 525 hours in total.

The relationship between the 99-percentile and the 98-percentile, in the conditions that prevail in Ireland, is roughly:

$$C_{99,\ 1\text{-hour}} \approx 2 \times C_{98,\ 1\text{-hour}}$$

In other words, a criterion of $C_{98,\ 1\text{-hour}} \leq 6\ ou_E/m^3$ is approximately equivalent to $C_{99,\ 1\text{-hour}} \leq 12\ ou_E/m^3$.

6. Dose-effect relationship

6.1 The relative properties of pig odours compared to other environmental odours

Evidently not all odours are the same in their ability to cause annoyance. To account for these differences in annoyance potential in quantitative terms is not that simple, however. That is the reason why most calculations used to predict the impact of odours involve the simplification of characterising odours in terms of detectability only, using the odour concentration, which does not take into account the different characters of odours. The odour concentration reduces the question of 'how strong and unpleasant is this odour' to a detection threshold, and the original odour is characterised in odour units, or multiples of the concentration at threshold. (See section 4.2.1 for more detail on interpretation of odour measurement results.)

This simplification is useful, as it allows calculations in concentration terms, compatible with the general concepts of air quality criteria.

It is important, however, to be aware of the limitations of this simplification, and to consider the characteristics of the odour at hand, relative to other odours.

The relative odour annoyance potential of pig odours, relative to other odours, is relevant to the question of assessment, in that it can assist in providing points of reference with criteria that have been established for other odours.

Exposure guidelines based on dose-effect relationships for a number of industries were established during the 1990s in the Netherlands[3] and range from $C_{98,\ 1\text{-hour}} \leq 0.5\ ou_E/m^3$ to $C_{98,\ 1\text{-hour}} \leq 3.5\ ou_E/m^3$, see also Table 7.

The relationship between the odour concentration of pig slurry and the perceived intensity has been established experimentally[12] (see Figure 3). Comparison with the intensity characteristic for broiler house odours shows that the increase in perceived intensity is less steep than broiler odours, which are particularly pungent because of their high ammonia content.

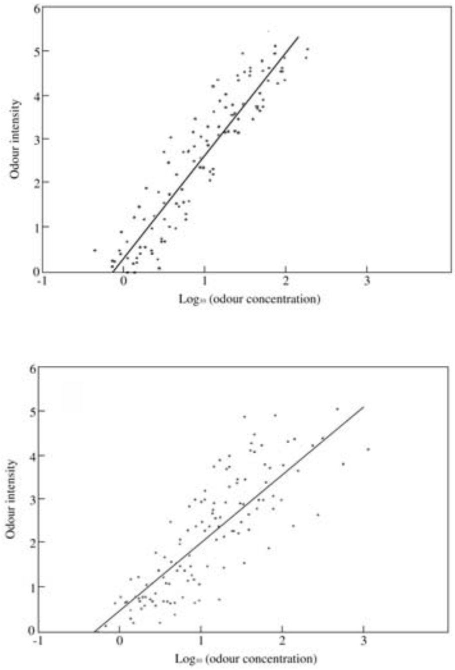


Figure 3: Relationship between odour concentration and perceived intensity, for broiler house odour (top) and the odour of pig slurry (bottom) after application. From Misselbrook TH, Clarkson CR, Pain BF: Relationship Between Concentration and Intensity of Odors for Pig Slurry and Broiler Houses. Journal of Agricultural Engineering Research 55: 163-169, 1993.

A straightforward approach to comparing the odour annoyance potential of different odours is to ask a group of people to rank a list of 20 descriptors of odours, according to like and dislike. This approach has been used in research for generic, everyday odours[13]. More recently, this approach has been applied to rank environmentally relevant odours, using groups of people who deal with odour annoyance professionally[14]. The ranking order of a list of 20 industrial and agricultural odours was found to be remarkably consistent, when applied to two groups of people attending an odour annoyance seminar (one group in the Netherlands and another in Germany). The results for the Dutch group are presented in Table 6.

The ranking is strictly on order, it does not provide a comparative magnitude. The results are relevant, in that odours from intensive livestock operations are ranked in the more unpleasant end of the list, but certainly not at the extreme end of dislike. Hedonic tone measurements for livestock odours were not identified in the review of literature for this report.

Although scientifically not very relevant, it is interesting to compare the ranking technique with odour exposure criteria that have been set for specific industries in the Netherlands. These criteria are only partly based on research, as they are also the result of a consensus building process between the regulatory agency and the industry involved[15]. These values can be seen, however, as an expression of the consensus reached in that society on the relative odour annoyance potential of these odours. In Table 7 the air quality criteria are listed, with their ranks from Table 6. The ranking is generally reflected in the air quality criteria that were agreed. Livestock odours are ranked similar to wastewater treatment plants, in terms of relative dislike, see Table 6. For wastewater treatment odours, a range of criteria exist in the Netherlands, ranging from $0.5 \leq C_{98,\ 1\text{-hour}} \leq 3.5\ ou_E/m^3$. In the United Kingdom, a limit value of $C_{98,\ 1\text{-hour}} \leq 5\ ou_E/m^3$ has been accepted in a planning procedure for Newbiggin-by-the Sea[16] as a reasonable criterion to demonstrate absence of nuisance, as required in the UK legislation.

Table 6: Ranking of 20 generic and 20 environmental odours according to like or dislike by a group of people professionally involved in odour management, in the Netherlands, 1997

Descriptor	Ranking	Ranking	Descriptor
Generic odours	**mean**	**mean**	**Environmental odours**
Roses	3.4	1.7	Bread Factory
Coffee	4.6	4.6	Coffee Roaster
Orange	5.8	5.1	Chocolate Factory
Cinnamon	6.0	8.1	Beer Brewery
Mowed lawn	6.4	8.3	Car Park Bldg
Soap	7.3	9.4	Charcoal Production
Hay	7.5	9.6	Frozen Chips production
Brandy	7.8	9.8	Eel smoking
Raisins	7.9	9.8	Car Paint Shop
Beer	9.3	9.8	Sugar Factory
Cork	10.5	9.8	Fragrance & Flavour Factory
Peanut Butter	11.1	11.2	Asphalt
Cleaning Agent	12.1	12.8	**Intensive Livestock Farming**
Sauerkraut	12.8	12.9	Wastewater Treatment
Wet Wool	14.1	13.2	Livestock Feed Factory
Paint	14.4	13.2	Refinery
Vinegar	14.8	14.0	Green Fraction compositor
Sweat	17.2	14.1	Landfill
Sour Milk	17.5	15.7	Fat & Grease Processing
Cat's Urine	19.4	17.0	Slaughter House

Within the descriptor 'livestock odours' pig odours are classified at the less favourable end of the spectrum of like and dislike. In Figure 4, relative nuisance from different types of livestock are shown, with pig odours forming the least liked extreme, in relative terms[in:17].

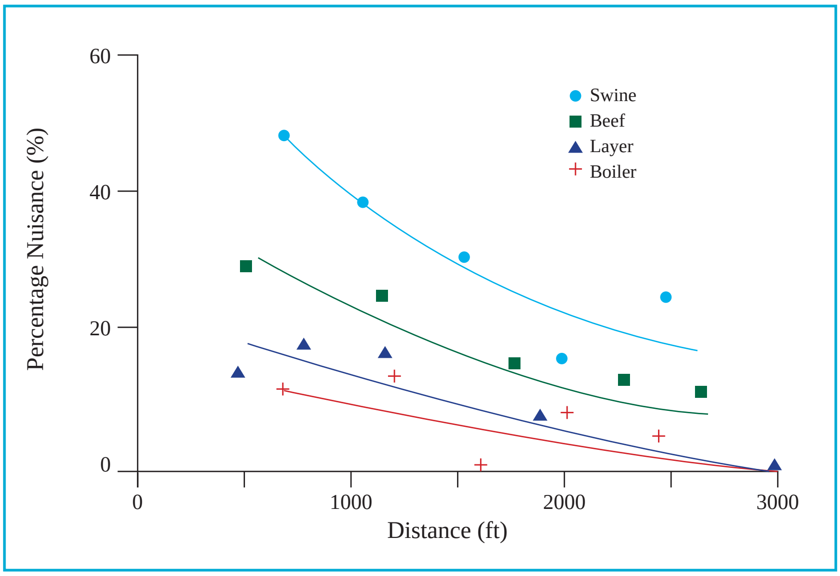


Figure 4 Relative nuisance perception for different livestock odours, expressed in relation to the distance to the livestock housing, source: Veenhuizen, 1996 [in:17]

6.2 Relation between odour exposure and percentage of population annoyed

Note: *This section reflects the results of a large-scale study into the relationship between exposure to pig odours and annoyance in the exposed population. The results of the study have been specifically interpreted to arrive at a framework of environmental quality criteria for application in Ireland.*

To establish air quality criteria for odours, with a view to assuring that exposure of odours is limited to levels that are acceptable from a public health and well-being perspective, we need to establish a dose-effect relationship describing the relation between exposure to odours in the environment and the resulting degree of annoyance in the exposed population. This epidemiological basis is indispensable for setting environmental criteria in a quantitative framework.

In this section the relation between calculated exposure to odours (dose) and percentage of the population experiencing annoyance (effect) will be discussed on the basis of epidemiological studies for a number of (bio-)industrial odour sources conducted in the late 1980's and 1990's [3] and a recent extensive study aimed specifically at pig odours[4].

In these studies the dose is determined by atmospheric dispersion modelling, using the odour emission rate as measured at source, with other data such as meteorology and topography, to calculate 98-percentile of hourly average odour concentration ($C_{98,\ 1\text{-hour}}$). The percentage of people annoyed is determined by drawing a sample from the residential addresses found in an area exposed to a certain level of exposure to odours (dose) and approaching these residents, typically by telephone, with a questionnaire. The residents are not informed that the questionnaire is aimed at assessing odour annoyance to reduce the probability of bias in the response. The responses to defined key questions are used to establish whether respondents are annoyed by odours. (see section 5.1.1). In some cases, the annoyance is classified on a scale, to differentiate between *annoyed and seriously annoyed.*

Table 7: Industry sector specific air quality criteria for odours, the Netherlands, and mean ranking score (see table 2)

Industry	Limit value $C_{98,\ 1\text{-hour}}$	Target value $C_{98,\ 1\text{-hour}}$	Questionnaire ranking
Bakeries	No limit value, >>5 ou_E/m^3		
Meat processing	≤ 1.5 ou_E/m^3	≤ 0.8 ou_E/m^3	
Grass dryers	≤ 2.5 ou_E/m^3		
Bakeries, pastry	≤ 5 ou_E/m^3		1.7
Coffee roasters	≤ 3.5 ou_E/m^3		4.6
Flavours & Fragrances	≤ 3.5 ou_E/m^3	≤ 2.0 ou_E/m^3	9.8
Wastewater treatment plant, greenfield site, residential dwellings in vicinity	≤ 0.5 ou_E/m^3		12.9
Wastewater treatment plant, greenfield site, rural area or industrial estate in vicinity	≤ 1.0 ou_E/m^3		12.9
Wastewater treatment plant, existing site, residential dwellings	≤ 1.5 ou_E/m^3		12.9
Wastewater treatment plant, existing site, rural area or industrial estate	≤ 3.5 ou_E/m^3		12.9
Livestock feed production	≤ 1 ou_E/m^3		13.2
Composting, organic fraction of domestic waste, greenfield site	≤ 1.5 ou_E/m^3	≤ 0.5 ou_E/m^3	14.0
Composting, organic fraction of domestic waste, existing facility	≤ 3.0 ou_E/m^3	≤ 1.5 ou_E/m^3	14.0
Slaughterhouses	≤ 1.5 ou_E/m^3	≤ 0.55 ou_E/m^3	17.0

In a recent paper these studies have been reviewed[3]. The raw data of previously reported studies were re-analysed, this time adding a factor to reflect the relative 'pleasantness', or odour annoyance potential for each odour type. (See also section 4.2). The results were analysed to establish a relation between dose (odour exposure) and effect (percentage of population annoyed). The statistical model applied in these studies shows a strong correlation for all but one of a dozen studied cases. For the combined data for all studies, the correlation coefficient r is 0.889. The review paper demonstrates that the correlation coefficient improves to r is 0.935 to 0.945 when an additional variable is introduced to represent odour annoyance potential.

The odour annoyance potentials for the odours involved were established in laboratory tests using assessors. The odours were presented at a defined odour concentration, e.g. 25 ou_E/m^3. Two methods were used, both leading to a ranking of odours according to their *annoyance potential*. Method a.) used paired comparison, while method b.) used a nine-point reference scale, with H_2S at providing a reference for scale value 2 on the unpleasant end and amylacetate referencing value 8 on the pleasant end of the scale. The ranking of the odours according to their 'pleasantness' is presented in Table 8 on this page. This table compares to Table 6.

When interpreting the results of the review paper[3] two issues must be kept in mind:

- The odour units used in the review paper are odour units as used in the Dutch NVN2820 standard. The relation to European odour units as defined in EN13725, as used throughout this report is: 1 ou_E/m^3 = 2 ou/m^3.
- The annoyance is expressed as percentage of questionnaire respondents seriously annoyed (%HA). This classification, particular to this paper, represents approximately the top third of all people 'annoyed'.

The relation between the percentage of respondents seriously annoyed and the calculated odour exposure, for all study cases combined, is:

$$\%HA = 4.775 \cdot \log(C_{98,\ 1\text{-hour}})^2$$

This implies that at an exposure level of $C_{98,\ 1\text{-hour}} = 5.3$ ou_E/m^3 the percentage of respondents seriously annoyed by odours is 10%. As pig odours rank among the odours with higher annoyance potential, this value is likely to be slightly lower for pig odours, although the paper does not give the equation for the dose-effect curve for pigs.

The specific dose-effect relationship for odour annoyance caused by pig odours has been established as recently as 1999, in a study involving approximately 2300 residents exposed in different degrees to odours from pig production units[4]. As a result, the dose-effect relation for pig odours is currently relatively well documented and can be used as a tool for predicting odour annoyance levels in a population.

The dose-effect relation was determined by studying the following variables:

Table 8: Ranking of (bio-)industrial odours according to their perceived 'pleasantness' as determined in two types of laboratory experiments.

Unpleasant	
Oil extraction	Rendering
Chemical plant	Oil extraction
Rendering	Chemical Plant
Pig Farm	Pig Farm
Sugar factory	Grass drying
Grass drying	Sugar factory
Frozen Chip production	Frozen Chip production
Wire coating	Pastry factory
Pastry factory	Wire coating
Cacao processing	Cacao processing
Tobacco processing	Tobacco processing
Pleasant	

- Odour exposure, calculated using dispersion modelling, as the hourly concentration at the 98-percentile of 1-hour averaged concentrations in a typical meteorological year
- Percentage of a sample of the population classified as 'occasionally or frequently annoyed' on the basis of their responses in a standardised questionnaire, using interviews by telephone (see section 5.1.1 for details).

The correlation between odour exposure and percentage of the population 'annoyed' turned out to be highly significant.

A significant conclusion was, that the percentage of respondents annoyed could be predicted adequately by establishing the exposure *due to the dominant source only,* defined as the individual source contributing most to the total $C_{98,\ 1\text{-hour}}$ odour exposure of the exposed location. Adding additional sources contributing to the overall exposure did not provide a better prediction of annoyance percentage. This finding is practically very useful, as it allows assessment of annoyance by considering the most dominant source only, when preparing an environmental impact statement.

In the study, differences between areas with different land use were determined, which reflects the Dutch regulatory practice of using a qualification of 'non-agricultural, urban and suburban', 'Villages in agricultural environment', agricultural housing' etc. In the study, a differentiation was made between *pig* *concentration areas*, which are effectively set aside to some degree to allow elevated levels of pig production, and *general usage* areas, outside concentration areas. Respondents in concentration areas who are employed in the pig production trade form a specific category.

The dose-effect curves for percentage annoyed, as predicted from calculated exposure ($C_{98,\ 1\text{-hour}}$) caused by the dominant source only, are shown in Figure 5.

The figure shows that:

- In the general public, exposed to pig odours from one piggery, 10% of the respondents are annoyed at an exposure level of $C_{98,\ 1\text{-hour}} \approx 1.3\ ou_E/m^3$.

- In a selection from general public of those resident in a pig concentration area, where pig odours form a feature of the odour context of the area, both those exposed to pig odours from one piggery and those exposed to odours from multiple pig units, 10% of the respondents are annoyed at an exposure level of $C_{98,\ 1\text{-hour}} \approx 3.2\ ou_E/m^3$.

- The most 'pig odour tolerant' selection from the general public was found in the pig production concentration areas, where pig odour is a feature of the odour context in the environment, historically. For this group, with the lowest annoyance sensitivity, the 10% annoyance level is reached at an exposure of $C_{98,\ 1\text{-hour}} \approx 6.3\ ou_E/m^3$.

- Those who are directly involved in agriculture were found to be the most 'pig odour tolerant' selection of the population. For this group, with the lowest nuisance sensitivity, the 10% annoyance level is reached at an exposure of $C_{98,\ 1\text{-hour}} \approx 13\ ou_E \cdot m^{-3}$.

Statistical analysis of the data yielded some remarkable conclusions:

1. The 'annoyance sensitivity' of people exposed to one single source was higher than for those exposed to two or more sources.

2. The annoyance percentage was best predicted by considering the one dominant source only. When exposure was calculated in this manner, the difference between respondents in one-source and multiple source situations was no longer apparent.

3. The annoyance sensitivity of people who are *directly involved* in agriculture was found to be significantly lower than that of the general population living in a similar area. This effect is even more pronounced for those living in 'pig production concentration areas' where the agricultural population displays a markedly more tolerant attitude, leading to lower levels of annoyance at a given exposure to odours than in all other groups.

4. Whether people lived in a rural or more (sub-) urban environment did not have a significant effect on their annoyance sensitivity. Only people living in 'pig production concentration areas' showed lower annoyance sensitivity than in other areas, indicating a higher tolerance to pig odour exposure.

The dose-effect relationships, differentiated for subgroups as discussed above, are shown in . The information as provided above can be the starting point for a set of limit and target values for exposure, associated with differentiated levels of protection against nuisance.

A level of 10 % of respondents annoyed has been chosen as a practical guide value, which is more than double the 'background' or 'baseline' level for odour annoyance, as assessed in areas not exposed to (bio) industrial odours. The percentage value of 10% is slightly less than the stated policy objective of the regulator in the Netherlands to limit the fraction of people annoyed by odours to 12%. Although this regulatory objective lacks a well-reasoned scientific motivation, is has been used in regulatory practice since 1985 in hundreds of licensing cases, with overall satisfactory results, for the Dutch regulatory environment[20].

Of course, the Agency will have to take into account specific conditions to set criteria for Irish conditions, reflecting a level of environmental quality and protection compatible with Irish society. Ideally, dose-effect relationships for Irish citizens in Irish conditions should be assessed, to confirm the findings obtained abroad.

The guide values for establishing exposure criteria are outlined below:

- The curve for *One source, non-agricultural residents* represents the group with the highest 'annoyance sensitivity'. This group consists of people with no professional involvement with the agricultural sector, exposed to the effects of a single source, in rural or (sub-) urban areas. This sub-group can be regarded as the group with the least tolerance to pig odours. However, it is likely to be the largest subgroup in the general public. This group has therefore been regarded in this study as *representative of the general public*. For this group, an annoyance percentage of 10% is associated with an exposure to pig odours of $C_{98,\ 1\text{-hour}} = 1.3\ ou_E/m^3$.

- The curves for *One source, non-agricultural residents, living in pig production concentration area and Multiple source, non-agricultural residents living in pig production concentration area* coincide, when only the one most dominant source is included in the calculation of exposure. These groups represent a selection of the general public with a lower sensitivity to annoyance. These people live in an environment where pig odours have become a feature of their environment, and pig production is apparently more accepted to take its place in that environment. This sample of the population can been regarded as representing *the general public, with intermediate annoyance sensitivity, showing an increased tolerance to pig odours as an existing element in the status quo of their residential environment.*

  For this group, an annoyance level of 10% is associated with an exposure to pig odours of $C_{98,\ 1\text{-hour}} \approx 3.2\ ou_E/m^3$.

- The curve for *two or more sources, non-agricultural residents living in 'pig production concentration areas'* (not shown in Figure 5) represents the sub-group of the general public with the lowest annoyance sensitivity. Although these residents had no involvement with the agricultural sector, they live in areas where pig production is a significant feature of that area. This subgroup has been regarded to represent *the general public, with the lowest annoyance sensitivity, showing increased tolerance to pig odours as significant element in the status quo of their residential environment.* To arrive at a maximum value for 'tolerable exposure, we have looked to this group, with the exposure calculated on the basis of all relevant sources of pig odour combined. For this group, 10% annoyance is associated to an exposure to pig odours of $C_{98,\ 1\text{-hour}} \approx 6.3\ ou_E/m^3$.

- The curve for *concentration area*, farmers represents a subgroup that can be characterised as the most tolerant in the survey, given their association with agriculture in pig production concentration areas. This group, associated with the source of the odours, cannot be considered to be representative for the general public. The exposure associated with 10% annoyance in these persons directly involved in agriculture in concentration areas is $C_{98,\ 1\text{-hour}} \approx 13\ ou_E/m^3$. This value is indicative as an absolute upper exposure limit, but is as such not usable as a starting point for an exposure guideline aimed at protecting the general public.

The exposure level of $C_{98,\ 1\text{-hour}} \approx 6.3\ ou_E/m^3$ associated with 10% annoyance in the most tolerant selection from the general public[4], combined with the finding[3] that for a selection of (bio)-industry odours 10% of respondents experiencing serious annoyance is associated with $C_{98,\ 1\text{-hour}} = 5\ ou_E/m^3$, underpins a suggested upper limit value for odour exposure to be set not higher than $C_{98,\ 1\text{-hour}} \leq 6\ ou_E/m^3$. This recommendation is based on a substantial set of data from independently conducted studies, as described above (*n* = approximately 620 respondents).

The value for the general public of $C_{98,\ 1\text{-hour}} \approx 1.3\ ou_E/m^3$ is associated with 10% annoyance in the general public underpins a target value for odour exposure at a value of $C_{98,\ 1\text{-hour}} \leq 1.5\ ou_E/m^3$, based on a substantial set of data (*n* = approximately 1500 respondents).

A framework of suggested limit and target values on the basis of the results of epidemiological dose-effect studies as discussed above is outlined in section 8.3.

7.1 Generic approaches to livestock odour management and regulation

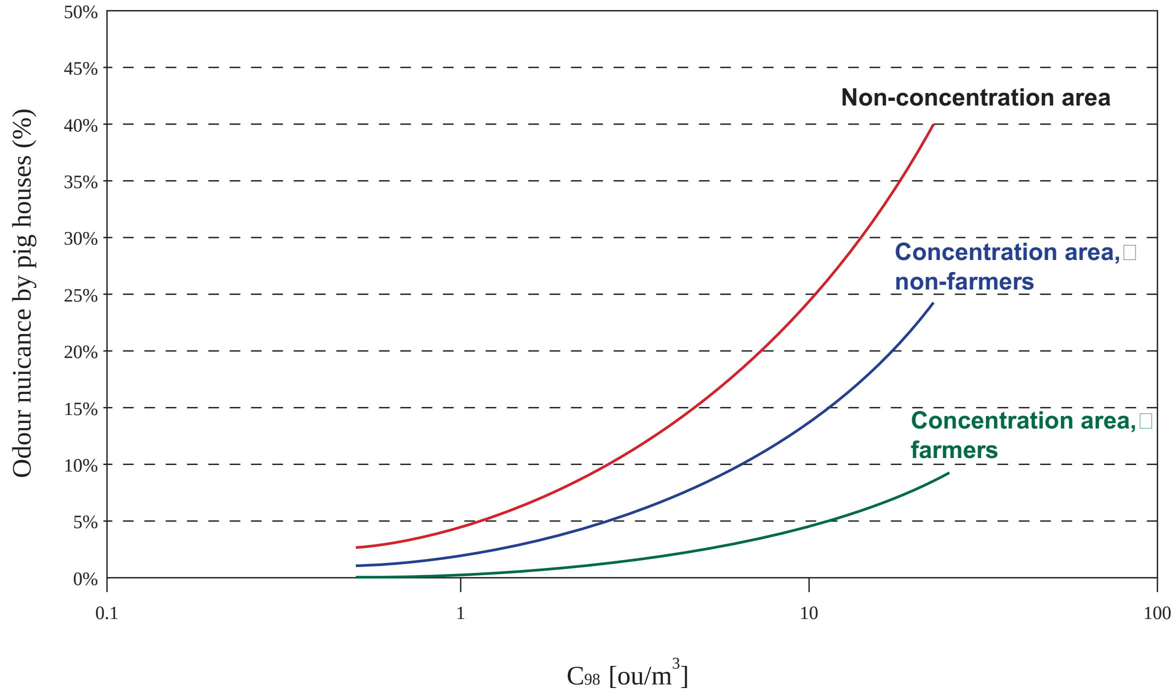


Figure 5 Relation between percentage of population experiencing 'annoyance' (effect) and calculated odour exposure (dose) for one-source situations, expressed as C98, the 1-hour averaged odour concentration at the 98-percentile for a normal meteorological year . Note: 2 Dutch ou/m^3 = 1 $ou_E \cdot m^{-3}$
(Source: reference [4] also presented verbally at conference with paper[37]).

7. Comparison of regulatory approaches in different countries

Pig producers have a responsibility to minimise the impact of their business on the environment, and to avoid 'loss of amenity' and nuisance occurring in the vicinity of their production site. Odours, as an environmental stressor, tend to have a reach well beyond the site boundary.

In many countries, nuisance law has existed for many years. This type of legislation is very general in its nature, often relying on appointed environmental health officers or law enforcement officers to make individual judgements on the question of whether the odour experienced constitutes a nuisance in legal terms.

To assist regulatory agencies in managing odour issues, a number of countries have issued guidelines, regulations or even legislation in their efforts to apply a regulatory mechanism to odours from pig production units.

The majority of these guidelines use a schedule of setback distances, based on the size of the facility expressed as total number of animals, to define the minimum distance between pig houses from dwellings in the vicinity, with a view to avoiding odour annoyance

This type of setback distance guidelines started to appear in the early 1970s and have been adopted in a number of countries. In some cases, the setback tables have been developed from their early, simple form into an elaborate mechanism, taking into account different types of housing, operational practices, usage of the surrounding area, cumulative effects of multiple pig producers, etc.

Although this approach provides a detailed framework for assessment, the basis for the setback distances is rarely based on systematic scientific observations. The first guidelines were published in the Netherlands in 1971 as a graph of setback distances versus the number of pigs[18]. These graphs were based on the limited observations of a handful of Health Inspectors. This provided a pragmatic approach that has been applied effectively for many years, in spite of the fact that the guidelines were based on very limited experimental data.

In a limited number of European countries, specific regulations for odours from livestock were introduced well before industrial odours became a regulatory issue, in the early 1980s. The more quantitative approach of measuring emissions and modelling their impact off-site, which was applied to industrial odour sources, was generally not applied to agricultural odours. For a variety of reasons, however, there is a tendency for the approach towards odour annoyance management in agriculture and in industry to converge. This development is a result of a variety of factors, such as the enlargement of the scale of pig production units, the tendency towards diversification of land use in rural areas and the introduction of IPC and IPPC for both industrial and livestock operations (over a certain minimum size).

Currently, data are becoming available which allow the setting of environmental targets for odour exposure on the basis of actual 'epidemiological' studies into the prevalence of odour annoyance as a result of exposure to pig odours[4]. The emission factors for pigs, in different stages of their life cycle, have been measured in detail, using standardised methods[5,10]. The availability of these data allows the design of an assessment framework that translates these scientific background data into objectives of a society in terms of environmental quality.

Summarising, there are three generic approaches to managing the impact of pig production odours in a regulatory framework:

1. **Nuisance Law approach:** *No Nuisance at the boundary*
   Assessment and enforcement on the basis of the individual judgement of inspectors

2. **Setback Distances:** *Pragmatic semi-quantitative approach based on experience*
   Assessment based on a schedule of distances depending on the number of animals, sometimes more elaborate to take into account operational

practice, land use in the vicinity, cumulative effects etc. Tables with setback distances have been used typically for relatively small pig units, e.g. ≤ 500 sows.

3. **Air quality criteria for odour exposure:** *Quantitative approach based on the dose-effect relationship*
   Assessment based on epidemiological research into the prevalence of annoyance caused by odours from pig production. These criteria can be implemented using the general approach common to air quality issues. Impact assessment is based on emission factors and atmospheric dispersion modelling. The approach in individual cases can be simplified for practical implementation similar to setback distance schedules, if the outcome is straightforward.

For the framework for assessment of the impact of pig odours in Ireland, the latter option is considered the best approach. A quantitative approach provides the best basis for judgements that are based on objective data, while leaving a margin of flexibility to allow more subjective factors to be taken into account in the licensing procedure.

7.2 Background to the use of quantitative odour exposure criteria

At the time of writing this report in 2001, there is no clear guidance available on the assessment of impacts of livestock odours in Ireland. The obligation to avoid nuisance does exist, however.

Some other European countries have moved towards the use of quantitative assessment methods for regulating odour exposure since the 1980s.

Authorities in the Netherlands have used quantitative air quality criteria for odours in licensing since 1985[19]. Initially, an overall air quality target was set for licensing industrial sources of odour. This regulation differentiated between existing sources and applications for new sources on greenfield sites. The limit value for existing sources was set at $C_{98,\ 1\text{-hour}} \leq 0.5\ ou_E/m^3$, while for new sources a stricter limit at a higher percentile was prescribed: $C_{99.5,\ 1\text{-hour}} \leq 0.5\ ou_E/m^3$.
Data collected by survey in 1990 in The Netherlands from populations surrounding 200 industrial odour sources where the exposure standard of 0.5 ou_E/m^3 for a maximum of 2% of all hours ($C_{98,\ 1\text{-hour}} \leq 0.5\ ou_E/m^3$) had been in place for some years, has shown that, when this standard is met, there are no justifiable complaints[20].

In 1995, a group of Dutch industries successfully lobbied to obtain a more lenient regulatory framework, which allowed differentiation between odours with a high odour annoyance potential (e.g. rendering) and those with a lower annoyance potential (e.g. coffee roasters, bakeries). This has resulted in a set of differentiated target values of between 0.5 and 3.5 ou_E/m^3 as a 98-percentile for industrial sources (see Table 7). A strict value of $C_{98,\ 1\text{-hour}} \leq 0.5\ ou_E/m^3$ is applied to very unpleasant odours, with a high odour annoyance potential, while more acceptable industrial odours are regulated to more lenient values, e.g. $C_{98,\ 1\text{-hour}} \leq 3.5\ ou_E/m^3$ (e.g. coffee roasting).[15]. Also, the regional and local authorities have been given more say and flexibility to take account of local conditions in the licensing process.

In the UK, the first instance of regulatory approval of this approach and an exposure standard of 5 ou_E/m^3 was in a Planning Inquiry held into a proposal for a new sewage treatment facility at Newbiggin-by-the-Sea in spring 1993. The Inspector in his report accepted this approach and stated that "he was satisfied that the evaluation undertaken demonstrated that the proposals would not give rise to a risk of unacceptable odour emissions beyond the boundary of the appeal site" (case ref. APP/F2930/A/92 206240)[16].

7.2.1 The reasoning underpinning the choice of odour exposure limit values varies.

In the UK literature[36], the reasoning underlying a choice of limit value is typically based on extrapolation of findings in laboratory studies, rather than relying on epidemiological data. The argument is that, by definition, 1 ou_E/m^3 is the detection threshold of 50% of a qualified panel of observers working in an odour-free laboratory using odour-free air as the zero reference (the selection criteria result in the qualified panel being more sensitive to a particular odourant than the general population). The recognition threshold is generally between 1 and 5 times this concentration (1-5 ou_E/m^3) and the concentration at which the odour may be considered to be a nuisance is between 5 and 10 ou_E/m^3, although this figure can be as low as 2 ou_E/m^3 for particular offensive odours. Laboratory research in Ireland by Carney and Dodd found that pig odours reach a *nuisance threshold* at between 2.3 and 9.6 times (average 4.8 times) the concentration at the detection threshold[21]

Although this argument provides a useful insight, it does not tell the full story. To fully consider the relationship between downwind odour concentration and nuisance, the length of time that a receptor is subject to a threshold concentration must be considered. For example, a 'faint odour' that can be perceived by a receptor for a few hours per year with those hours dispersed throughout the year, would be unlikely to cause a nuisance. The same concentration perceived for the majority of the year, undoubtedly would. Relationships between concentration, time of exposure and resulting nuisance (or freedom of nuisance) can only be determined by surveying populations living in the vicinity of odour sources, using an epidemiological approach.

There is a need for a standardised quantitative method for the measurement of 'odour annoyance potential' to differentiate between different odours. It should allow the translation of knowledge on the dose-effect relationship, collected in an epidemiological survey, to another odour, using a more simple and effective laboratory method to do so. Such a method is not yet available. A feasibility study to review the options to develop a method for determining annoyance potential of odours has been completed, however, giving an overview of the options and identifying the steps needed to develop and validate the required method[1]. The prospects for developing a standardised method for determining annoyance potential are promising.

Until a proper method for odour annoyance measurements is available, it will be difficult to relate specific odours to dose-effect relationship information for other odours, on the basis of comparing the odour annoyance potentials. Until a method for assessing odour annoyance potential becomes available, the best indicator for annoyance potential is probably the use of hedonic tone, or a scale of like and dislike.
For now, the best possible basis for odour exposure criteria is the use of actual epidemiological research into the prevalence of odour annoyance, as a result of exposure to that specific odour. This dose-effect relationship has recently been established for pig odours in the Netherlands[4]. It should be taken into account that the dose-effect relationship depends on the population involved. To transfer results of research in one country to another country requires some interpretation, to arrive at odour exposure criteria best suited to the conditions in that country. Environmental quality standards are set to reflect the requirements and aspirations of a society, and hence contain a policy judgement, even if the principles are laid out using scientific data.

7.3 Overview of livestock odour guidelines in different countries

The guidelines for limiting the impact of pig odours in different countries tend to reflect the history and structure of the pig industry in each national setting. Most regulations and guidance use setback distances as the main instrument to reduce the impact of pig odours on people living in the vicinity. In some cases (UK) the guidance focuses entirely on good practice, in the form of a Code of Good Agricultural Practice for the Protection of Air by the Ministry of Agriculture, Fisheries and Food (MAFF).

Setback distances are in some cases suggested in general terms, as a 'desirable distance' (USA), or as a minimum suggested distance (Ireland, currently). In other countries, more elaborate guidance has been developed, allowing a more precise determination of setback distances based on a number of factors, such as:

- The number of animals on the site, specified to their stage in the lifecycle
- The design and operation of the facility (e.g. housing type, manure storage, feed composition)
- The use of the vicinity (e.g. neighbouring farmhouses only, isolated dwellings, residential developments)

Examples of countries where such detailed schedules are used to determine setback distances for licensing purposes in specific cases are Germany, Austria and The Netherlands.
The approach towards reducing pig odour impact has been described in detail in the annexes to this report for:

Germany, the Netherlands, the United Kingdom, New Zealand and the United States.

In this chapter, a short overview is provided for each of these countries, followed by a comparison of the different regulatory approaches, by comparing the setback distances for fictitious pig production sites.

7.3.1 Germany

The law concerning air quality issues in Germany is the Bundes Immissionsschutz Gesetz (known as 'BimSchG'), or the Federal Immission Control act of 1990.

All odours from any commercial installation are considered an annoyance, according to §3 of 'BimSchG'. For licensing and enforcement, however, the issue is to determine whether the annoyance constitutes a 'significant disturbance', based on the 'relevance of the annoyance'. However, the 'BimSchG' does not provide for criteria to determine when an annoyance becomes a significant disturbance (nuisance).

Criteria on how to achieve the general principles concerning air quality are not provided for in the BimSchG, nor in the second relevant official regulatory document, which provides technical guidance for specific industries,. The *Technische Anleitung zur Reinhaltung der Luft*, or TA-Luft, details the technical measures, expected to be applied in different sectors of industry and agriculture, including methods for assessment. The TA-Luft is available in English, titled: *Technical Instruction on Air Quality control.*

The TA-Luft defines a maximum 'odour frequency', as an ambient air quality characteristic, but does not specify a method to assess this parameter. In 1994 a method was introduced by the Department of the Environment of Nordrheinland Westfalen. The document is available in English translation: *Determination and Evaluation of odour immissions - Odour exposure guideline*

This method is based on a method for long-term field panel observations, in which the fraction of 'odour hours' is determined by a team of assessors assigned to make observations at intervals over a period several months at pre-defined locations on a grid around the source in question. The method has been applied on pig units[9]. This method can be applied to determine licensing applications.

However, in most cases, a technical guideline is applied, that provides detailed advice on the design and operation of pig units and other livestock operations.

The national standard, VDI3471:1986, defines the practice for reducing the impact of pig production units. Setback distances are determined on the basis of a table to establish the number of Grossvieheinheiten (1 GV is equivalent to 500kg live weight). The number of GV is then related to the required minimum setback distance using a graph. The setback distance graph gives distances for up to 750 GV, approximately equivalent to 575 integrated sows in an Irish unit. A points system is used to characterise the operational practice and design, which is accounted for in different curves on the setback distance graph.

For a 400 sow unit, which is close to the Irish licensing limit, the setback distance would be between approximately 390 and 620m, depending on the number of points.

A more detailed description, including the distance graph, is given in Annex A.1.

7.3.2 The Netherlands

Setback distances are determined on the basis of a graph relating 'pig units', equivalent to a fattener, to setback distances. Different curves are given, depending on the land use in the vicinity. Different graphs have been used since the first publication of a guideline of this type, in 1971. Currently the graphs from the 1985 guideline are prescribed, providing graphs for production units of up to 2,500 pig units (equivalent to fatteners). A new guideline was proposed in 1995, with an identical set of setback distance curves. However, the description of categories of land use to which these curves were to be applied was modified, effectively leading to a more lenient policy on pig odours. However, the guideline as revised in 1995 has been judged to be too lenient in a number of cases by the State Council, the appeal court for planning decisions. A policy review by the Ministry of Public Planning and the Environment is now ongoing

(1999-2001). This review, which involves detailed research into the actual annoyance experienced at different levels of exposure to pig odours, is expected to lead to a more restrictive system based on air quality criteria.

A more detailed description, including the distance graph, is given in Annex A.2.

7.3.3 United Kingdom

The Environmental Protection Act of 1990 provides the legal framework for avoiding and controlling odour nuisance in the United Kingdom. The Environmental Health department of the Local Authority is responsible for its enforcement. Under Part III, Section 79 of the Act, the local authority has a duty to inspect their area and detect any statutory nuisance. Reasonably practicable steps are to be undertaken to investigate complaints by residents made to them.

Where a local authority Environmental Health Department is satisfied that a statutory nuisance exists, or is likely to occur or recur, it has a duty to serve an abatement notice under Part III, Section 80 of the Act requiring:

- the abatement of the nuisance or prohibiting or restricting its occurrence or recurrence; and

- the execution of such works and the taking of such other steps as may be necessary for these purposes.

When appropriate action is not taken as a result of an Abatement Orders, significant fines of up to 20,000 pounds can be imposed.

The law on statutory nuisance is far from straightforward. A key problem is that no criteria are provided to decide when occurrence of an odour constitutes a nuisance, and when it is acceptable. The system relies heavily on the individual judgement of the Environmental Health Inspector. In practice a wide variety of licence conditions occur.

Planning consents have to be granted on the basis of the Town and Country Planning (General Permitted Development) Order of 1995 (GPDO). New livestock facilities, such as livestock buildings, slurry storage facilities, and extensions or alterations to such facilities, need planning permission when these will be within a distance of 400 m from the boundary of any protected buildings (such as residential houses or schools).

Under the Town and Country Planning (Assessment of Environmental Effects) Regulations of 1988 an environmental assessment is to be carried out for certain types of major project which are likely to have significant effects on the environment. For livestock units this requirement is likely to apply to new pig units of more than 400 sows or 5000 fatteners and new poultry units of more than 100,000 broilers or 50,000 layers.

In planning procedures, the use of odour modelling with application of a criterion of 5 ou_E/m^3 as a 98-percentile of hourly values has been accepted as an acceptable approach to demonstrate that no statutory nuisance would arise, in a planning enquiry involving a wastewater treatment plant at *Newbiggin-by-the-Sea*, Northumberland, planning reference APP/F2930/A/92 206240, UK, 1993[16].

The main document providing guidance is:

- *The Air Code*, Code of Good Agricultural Practice for the protection of Air, revised 1998, Ministry of Agriculture, Fisheries and Food and the Welsh Office Agriculture Departments, October 1998.

The Code provides general guidance on the legal background, and on good practice for production., The main part of guidance on odours is given in Part B of the Code, which contains a wealth of sound general advice, but is remarkably limited on technical detail and quantitative assessment and management information. The Code does not contain any specific recommendation on setback distances, other than suggesting that any pig unit located at less than 400 metres from residences should take extra care in implementing the advice given in the Code.

For details on the Code of Practice, see Annex A.3.

7.3.4 United States of America

The regulations for odour in the United States of

America vary from state to state. The main legal basis for the regulations is the nuisance law. Various states have guidelines specifically aimed at managing odour emissions from pig units. In Annex A.4 a guideline issued by the EPA in Texas[17] is described in more detail.

In 1994, the American Society of Agricultural Engineers indicated that a 'desirable distance' for siting livestock facilities in general is 1600 meters from housing developments and 400 to 800 meters from neighbouring domestic dwellings.

The EPA guidance indicates that the setback distance should be at least 3.6 kilometres and preferably 7.2 kilometres for 'larger facilities'.

Details on US swine odour guidelines are provided in Annex A.4.

7.3.5 New Zealand

A detailed Code of Practice is applied in New Zealand, within the general legal framework of the nuisance law. The New Zealand Code of Practice (CoP) contains two types of setback distances:

- Fixed setback distances, that must be observed in all cases, regardless of the size of the production unit

- Adjustable setback distances that depend on the size of operation and a set of correction factors for site-specific operational characteristics.

The adjustable setback distances must be applied to pig production units with 2000 pigs or more.
For any piggery of more than 5000 pigs, the potential to create adverse effects needs to be determined on an individual case basis. The size of the buffer zone for such a piggery is determined to reflect this assessment.

Setback distances are determined on the basis of the P-factor, which counts all pigs older than 70 days. Breeding units with weaners only are counted using a conversion of 1 breeding sow = 5 pigs.

For an integrated unit of approximately 400 sows (2000 P-units in New Zealand), setback distances in excess of between 500 and 2000 meters would apply, depending on land use in the vicinity. Obviously, the New Zealand setback distances are quite strict, reflecting the availability of land and the high priority given to environmental quality in that country.

For details on the New Zealand Code of Practice, see Annex A.5.

7.3.6 Comparison of setback distances in different countries for fictitious pig units

The nationally advised practice, guidelines and regulations are compared for a number of countries, in general terms, by applying their particular approach to pig production units of a certain size. The comparison is not as detailed as the legal application in the country might require, but serves to illustrate differences in expectations of environmental quality for odour impact in the societies involved. The results are presented in Table 9.

Table 9: Comparison of (approximate) setback distances according to advice, guidelines and regulations in various countries. Minimum values are marked yellow, values for domestic dwellings green

Comparison of setback distances for pig units in different countries. Comparable criteria indicated in one colour.	Unit used or graph	600 sow integrated unit
Germany		
Graph input is the number of Grossvieh-units [GV] (equivalent to 500 kg live weight)	GV	785
Operations rating 25 points	m	700
Operations rating 50 points	m	620
Operations rating 75 points	m	550
Operations rating 100 points	m	470
Netherlands		
Graph input is the number of 'pig units' [mve] (equivalent to a fattener)	mve	3856
Category 1 (1995) - residential areas	m	520
Category II - (1995) dwellings in clusters and villages	m	400
Category III - (1995) isolated clusters of dwellings in rural area	m	210
Category IV - (1995) Farm houses	m	190
Ireland, currently		
Minimum suggested setback distance only	m	>400
Ireland, proposed		
Existing piggery, 600 sow integrated,limit value: minimum suggested setback (receptor location to the SW)	m	450
Existing piggery, 600 sow integrated, limit value: maximum suggested setback distance (receptor location to the NE)	m	650
Existing piggery, 600 sow integrated, limit value: minimum suggested setback (receptor location to the SW)	m	600
New piggery, 600 sow integrated, limit value: maximum suggested setback distance (receptor location to the NE)	m	900
USA		
ASEA,1994 ‘desirable’ setback distances		
Residential areas	m	1600
Dwellings, minimum suggested	m	400
Dwellings, optimum suggested	m	800
EPA guidance for 'Larger facilities'	m	3600
New Zealand		
Residential area, urban	m	2000
Place of public assembly	m	1500
Rural dwelling	m	500

8. Proposed framework for impact assessment with a view to licensing

8.1 Scope of impact assessment framework

The proposed framework for assessing the odour impact of pig production units that is outlined in this chapter has a clearly delineated scope:

- The framework aims to assist the Agency in assessing the odour impact of pig production units in licensing procedures.
- The assessment framework is suitable for existing pig production units and for new projects in greenfield locations.
- The impact of odours released from land-spreading operations is outside the scope of this study.
- As the issue of planning is outside the authority of the EPA, issues and instruments of planning are outside the scope of the assessment framework, while recognising that sound planning is the most effective method of protecting the interests of the public and of the pig producers.
- The framework does not differentiate in assessing the impact for a single sensitive receptor, such as a residential house, or larger numbers of dwellings.
- The framework is aimed at assessing the situation as it is described in the licence application and will not consider potential changes in the configuration through building or change of use.
- The framework is aimed at assessing pig production units that require a licence, according to the First Schedule to the EPA Act, 1992, which states:

6.2. The rearing of pigs in installations, whether within the same complex or within 100 metres of that complex, where the capacity exceeds 1,000 units on Gley soils or 3,000 units on other soils and where units have the following equivalents:
1 pig = 1 unit
1 sow, including progeny = 10 units

Implementation of a guideline based on the proposed framework will require careful consideration of the transitional phase, taking into account the historical development in which dwellings were previously allowed to coexist with pig units in situations where the buffer zones were insufficient. The issue of how to achieve such a transition is an essential aspect of policy implementation. However, being an issue of regulatory policy, it is beyond the scope of this report.

A consultation process involving the pig industry sector should form part of the implementation process, to ensure that its application in the licensing process is practicable.

8.2 Legal framework

8.2.1 *European legislation*

As a result of implementation of European Community guideline 97/11/EG, and a more recent amendment in Regulation SI no. 93, 1999 in the Regulations on Environmental Impact Assessment, an environmental impact assessment is required for all pig production units, which have

> *'………..installations for intensive rearing of pigs....which would have more than 2000 places for production pigs (over 30kg) in a finishing unit, more than 400 places for sows in a breeding unit or more than 200 places for sows in an integrated unit'.*

The European Council Directive 96/61, concerning Integrated Pollution Prevention and Control (IPPC) is relevant to pig production. According to the requirements of article 16, the Best Available Techniques (BAT) are to be identified for the European Intensive Livestock Industry, including pig production.

The IPPC directive defines BAT in its article 2, sub 11:

> ***"Best Available Techniques"*** *means the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for*

emission limit values designed to prevent and, where it is not practicable, generally to reduce emissions and the impact on the environment as a whole.

*"**Techniques**" include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned.*

*"**Available**" techniques mean those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator.*

*"**Best**" means most effective in achieving a high general level of protection of the environment as a whole.*

When determining BAT the following considerations must be taken into account, as listed in Annex 4 of the directive:

Considerations to be taken into account generally or in specific cases when determining best available techniques, as defined in Article 2 (11), bearing in mind the likely costs and benefits of a measure and the principles of precaution and prevention:

1. *The use of low-waste technology;*
2. *the use of less hazardous substances;*
3. *the furthering of recovery and recycling of substances generated and used in the process and of waste,where appropriate;*
4. *comparable processes, facilities or methods of operation which have been tried with success on an industrial scale;*
5. *technological advances and changes in scientific knowledge and understanding;*
6. *the nature, effects and volume of the emissions concerned;*
7. *the commissioning dates for new and existing installations;*
8. *the length of time needed to introduce best available techniques;*
9. *the consumption and nature of raw materials (including water) used in the process and their energy efficiency;*
10. *the need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it;*
11. *the need to prevent accidents and to minimise the consequences for the environment;*
12. *the information published by the Commission pursuant to Article 16 (2) or by international organizations*

It should be noted that the identification of BAT at individual pig- or poultry farms is not necessarily the same for all European farms. The so-called "local aspects" may influence the selection of BAT between Member States, or even between pig- or poultry farms within a Member State. Relevant local aspects are for example nuisance (odour, noise, coarse dust) and local air or water quality.

8.2.2 Irish legislation and guidelines

The European requirement for environmental impact statements is roughly compatible with the licensing requirements set out in the First Schedule to the EPA Act of 1992. The Act implies that licensing is required for any units that fall within the following description:

6.2. The rearing of pigs in installations, whether within the same complex or within 100 meters of that complex, where the capacity exceeds 1,000 units on Gley soils or 3,000 units on other soils and where units have the following equivalents:
1 pig = 1 unit
1 sow, including progeny = 10 units

Integrated Pollution Control (IPC) licensing will become a requirement for pig production units over a certain size. The dates at which existing units should have applied for a licence, according to their size, are:

>10,000 pig units	10 March 1998
>7,000 pig units	9 June 1998
>6,000 pig units	1 September 1999
>5,000 pig units	4 April 2000
>4,000 pig units	5 September 2000

EPA publications relevant to IPC licensing are:

- Integrated Pollution Control Licensing - Application Form, Pig and Poultry sectors
- Integrated Pollution Control Licensing - Application Guidance Note, Pig and Poultry sectors
- Integrated Pollution Control Licensing - Guide to Implementation and Enforcement in Ireland
- Integrated Pollution Control Licensing - BATNEEC guidance note for the Pig Production Sector

All pig units should comply with the existing BATNEEC guidance note for the pig production sector:

- *Integrated Pollution Control Licensing. BATNEEC Guidance Note for the Pig Production* Sector, Revision 1 - February 1998, Environmental Protection Agency, ISBN 1 8999965 36 X, Wexford, Ireland, 1998

This BATNEEC guidance is of a very general nature. The main issues raised, as far as they are relevant to the reduction of odour impact, are:

1. Section 4.3: *Pig units should be sited a distance of preferably not less than 400 metres from the nearest neighbouring dwelling and all operations on site shall be carried out in a manner such that air emissions and/or odours do not result in significant impairment of or significant interference with amenities or the environment beyond the site boundary.*

2. Section 4.4:
   Minimisation of odour emissions by:
   - Adequate cleaning of pig houses between batches.
   - Using adequate bedding in litter based pig housing.
   - Provision of adequate manure storage capacity.
   - Stocking pig units at design level.
   - Designing ventilation system to facilitate efficient operation including maintenance.
   - Filling and emptying liquid manure storage tanks from below the surface of the stored manure, where feasible.
   - Minimising the agitation of manure.

3. Section 4.5:
   Odour emissions should be contained by:
   - Reducing uncontrolled air movement
   - Filling and emptying liquid manure storage tanks from below the surface of the stored manure, where feasible
   - Transporting manure in suitably contained, leak proof vehicles
   - Minimising the agitation of manure
   Minimising the generation of odours during meteorological conditions which favour the spread of odours
   - Landscaping pig houses using shelter belts.

   Carcasses should be stored on site in covered containers and transported to a rendering facility in covered, leak proof containers as soon as practical and at least once per week.

4. Section 5.1: Describes the requirements for compliance monitoring
   Periodic monitoring of air quality with regard to odour nuisance at the boundary of the site and spreading areas as per licence

This report outlines a wider range of methods and techniques to reduce the impact of odours from pig production units. These methods will not all necessarily fall within the scope of BATNEEC or BAT.

8.3 The proposed assessment framework: general principles and odour exposure criteria

The assessment framework aims to define a set of criteria for odour exposure to achieve a common environmental quality objective in licensing procedures.

The propensity to experience annoyance caused by environmental odours, or annoyance sensitivity, is variable in a population of residents. Due to the wide range of *annoyance sensitivity* of individuals, a zero-impact approach is not realistic. The aim is to set environmental quality criteria for odours associated with an *acceptable level of annoyance*, sufficiently low to prevent nuisance. The required level of protection is to some degree a political choice, reflecting the expectations of environmental quality of the society in question. These expectations are not only determined by human physiological characteristics, but also reflect the expectations of environmental aesthetic quality. These expectations are a function of the social, economic and cultural outlook of a particular society at any given moment.

The core of the framework is a set of target and limit values for calculated odour exposure. Using emission factors for the animals in a given production unit, which may be adjusted for low-emission housing types and other mitigating factors, the odour exposure in the vicinity can be calculated, using atmospheric dispersion models.

For straightforward cases, a simplified calculation method can be used to determine whether the impact is well within the target values. If that is the case, no actual modelling is required. If the situation is 'borderline', a modelling exercise is necessary to assess the impact specifically for the location in question.

The calculated odour exposure is expressed as a value for the one-hour average odour concentration that is not exceeded during 98% of all the hours in a year with average weather conditions. This value is the 98-percentile of all calculated hourly concentrations, or $C_{98,\ 1\text{-hour}}$ in short, and is expressed as odour concentration in European odour units per cubic metre (ou_E/m^3) This value is obtained using the emission rate (estimate), combined with the characteristics of the emissions (height of emission point, exit velocity, location), in a mathematical model for atmospheric dispersion. These models can take the local topography, obstacles in the wind flow and meteorological conditions into account.

The environmental quality targets are based on extensive dose-effect studies that were carried out in the Netherlands in 1999, involving more than 2303 people living in the vicinity of pig production units[4], see section 6.2. In these studies the percentage of the exposed population experiencing odour annoyance was determined using a standardised telephone questionnaire method (see section 5.2.1.1). The person was classified as 'annoyed' if they experienced '*occasional or frequent annoyance because of livestock housing units*'.

In proposing the environmental quality criteria for Ireland, the general objective has been to reduce the percentage of the population 'annoyed' by odour exposure to less than 10% of the resident population in the vicinity. The choice of this level of annoyance to be 'acceptable' cannot be made on purely scientific grounds. It is a pragmatic value, based on the experience accrued from developing an odour policy in the Netherlands, where a policy target of 12% annoyance was formulated in 1988 [23]. The experience with licensing in the Netherlands, using criteria on that basis, supports the feasibility of that value, and its practical effectiveness. However, it must be clearly stated that this practical experience, built up in one country, can only provide a starting point for choosing an appropriate environmental target for Ireland. In the end, such an environmental target reflects the ambitions and requirements of a society, and is, therefore, a matter of policy, supported by scientific information.

At the selected level of annoyance, the risk of annoyance developing to nuisance is limited, in most circumstances, but not excluded. Nuisance may still occur in unfavourable situations, which can be determined by secondary factors such as disrupted community relations, a history of 'odour incidents' on the production unit, other environmental stressors (noise, dust), etc.

The 'annoyance sensitivity', or the propensity of a population to be annoyed by odours, at similar exposure levels, has been found to differ. The highest annoyance sensitivity is found in situations where one pig production unit is the cause of the exposure, and where those exposed are not employed in the agricultural sector. The lowest annoyance sensitivity was found in people who were employed in the agricultural sector, exposed to the cumulative pig odours originating in two or more pig production units, living in areas where pig production is the predominant economic activity.

Using dose-effect relationships that were established experimentally in a large-scale study[4] as a starting point, a three-tiered set of limit and target values was defined for impact assessment in Ireland. These odour exposure criteria aim to define ‘acceptable odour exposure’ that should not be exceeded at locations that can be classified as a ‘sensitive receptor’ for odours, as described in section 8.4. The environmental quality criteria are:

- **Target value: $C_{98,\ 1\text{-hour}} \leq 1.5\ ou_E/m^3$**
  The target value provides a general level of protection against odour annoyance for the general public, aiming to limit the percentage of people experiencing some form of odour-induced annoyance to 10% or less. The target value is to be used as an environmental quality target for all situations.

  The target value is achieved when the calculated odour exposure for all locations of odour sensitive receptors is less than an hourly average odour concentration of 1.5 ou_E/m^3 in 98% of all hours in an average meteorological year.

- **Limit value for new pig production units: $C_{98,\ 1\text{-hour}} \leq 3.0\ ou_E/m^3$**
  The limit value for new pig production units provides a minimum level of protection against odour annoyance, aiming to limit the percentage of those experiencing some form of odour-induced annoyance to 10% or less in the general public, assuming some degree of acceptance of the rural nature of their living environment.

  The limit value for new pig production units shall not be exceeded in the vicinity of new pig production units to ensure a minimum environmental quality.
  The limit value for new pig production units is complied with when for all locations of odour sensitive receptors the calculated odour exposure is less than an hourly average odour concentration of 3.0 ou_E/m^3 in 98% of all hours in an average meteorological year.

- **Limit value for existing pig production units: $C_{98,\ 1\text{-hour}} \leq 6.0\ ou_E/m^3$**
  The limit value for existing pig production units provides a minimum level of protection against odour annoyance, aiming to limit the percentage of people experiencing some form of odour-induced annoyance to 10% or less, in the most tolerant selection of the population.

  The limit value for existing pig production units shall not be exceeded in the vicinity of existing pig production units to ensure the minimum environmental quality in an agricultural setting. A phased plan must be made to reduce the odour impact, with time, to the limit value for new pig production units and, eventually, the target value.
  The limit value for existing production units is complied with when for all locations of odour sensitive receptors the calculated odour exposure is less than an hourly average odour concentration of 6.0 ou_E/m^3 in 98% of all hours in an average meteorological year.

These criteria for odour exposure aim to provide a framework that can be used to attain a general environmental quality in Ireland, while recognising that in some cases existing pig production units may need a considerable period of time to achieve that target. In some cases, the time allowed will have to take into account the cycle of normal replacement of assets such as housing, to allow implementation of a structural solution.

For those situations, a limit value is set that will reduce the impact of odours to a level deemed acceptable for the most tolerant sections of society, with a strong affinity with the agricultural sector.

As a general principle, however, a target value is set to ensure that, with time, an environmental quality is achieved throughout the country that allows a diversified use of the countryside, not excluding or limiting recreational and residential use.

8.4 Definition of sensitive receptors

To make the concept of ‘impairment of amenity’ operational, it is useful to determine what objects or structures, intended to be used by people, constitute a sensitive receptor. To decide whether a location should be classified as an odour sensitive receptor, the following issues must be considered:

- Is the facility for permanent use, throughout the year?
- Is the facility suitable as overnight accommodation?

- What is the type of activity associated with the facility (work, recreation, transport, residential, transportation)

All facilities where people can stay overnight and are permanently used are considered sensitive. In general terms, the more people consider the facility as their 'territory' and the less options they have to extract themselves from the situation in an episode of exposure, the more 'sensitive' the facility is.

The following table lists examples of sensitive receptors:

- *Residential dwellings,*
- *Visitor accomodation (hotels, B&B, guesthouses),*
- *Hospitals or nursing homes,*
- *Schools,*
- *Churches,*
- *Holiday and weekend dwellings,*
- *Campsites, and caravan parks,*
- *Sports facilities,*
- *Offices.*

8.5 Emission factors

Table 10 lists emission factors that are most suitable to use for odour impact assessment. The emission factors are differentiated for the category and weight of the animal. The data are derived from a Dutch study including conventional partly slatted pig houses[5,10,24], similar to those most common in Ireland, as well as a number of low-emission housing systems. The recommended emission factors for impact studies are based on Dutch data as these were used to calculate exposure in the dose-effect studies[4] discussed in section 6.2 that underpin the air quality criteria proposed in this report. Data from other countries are summarised in Table 10 and are discussed in more detail later in this section.

If an applicant proposes to use lower values than those provided in the emission factor table, these figures must be supported by measurement results. The measurements shall be carried out according to the standard prEN13725, and the emission factors expressed in ou_E/s.

Table 10: Recommended emission factors for pigs at different stages in the life cycle in European odour units per second (ou_E./s), and a summary of measured values from Netherlands, Belgium and the United Kingdom.

Category of animal	Recommended emission factors Emission per animal	Emission rate per animal						Emission rate/kg	
		Netherlands	Belgium			UK, converted to ou_E/m^3 Calculated for animal of 85 kg			
			annual	summer	winter	mean	Max	mean	max
		ou_E/s	ou_E/s	ou_E/s	ou_E/s	ou_E/s	ou_E/s	$ou_E.kg^{-1}.s^{-1}$	$ou_E.kg^{-1}.s^{-1}$
Fatteners, conventional, fully slatte						36	128	0.43	1.50
Fatteners, conventional, partially slatted	22.5	22.4	25.4	32.7	15.4	19	47	0.22	0.55
Fatteners, restricted emitting area below slats	10	9.6							
Fatteners, cooling of slurry surface below slats	11	10.8							
Fatteners, flushing twice/day below slats	11	10.9							
Fatteners, straw bed, scraped						20	53	0.24	0.63
Weaners, conventional, fully slatted	6	5 to 16.3	3.3	3.8	2.8				
Farrowers, conventional, fully slatted	18	17.8	17.2	20.1	14.5				
Dry sows, conventional	19	19.0	44.6	52.6	34.8				
Dry sows, group housing with feeding station	7	6.8							
Gilts	20								
Boars	20								
Fatteners, conventional, with air scrubber (acid)	30%	29%	scrubber removal efficiency						

The data that were obtained in the Netherlands were derived from a long-term research project, following a detailed protocol for evaluating emissions from different types of livestock housing[10]. The sampling programme stretched over two periods of several weeks each, one in winter conditions and one in summer conditions. Preliminary results were reported in 1997 including an emission rate for fatteners in a conventional housing system with partly slatted floors of 22.6 ou_E/s per animal at a mean ventilation rate of 33.3 m^3/hour/animal[5]. The full results, published more recently[10], are summarised in Table 11. Each emission factor in that table is based on 20 observations. The observed variations were considerable, both between farms and temporal variations within a farm, with coefficients of variation (standard deviation as a percentage of the mean) typically in the order of 25 to 50%. The variation for weaners was considerably larger, which prompted a repeat of an initial sampling run. The study indicated that the emission rate was significantly affected by the ventilation rate.

The same correlation between ventilation rate and emission factor was established in recent research in Belgium[35], using compatible methodology and olfactometry. Initial results of the ongoing study into emission factors from pig production in Belgium were reported recently[35] and are summarised in Table 12. When the emission for a production unit was corrected for the actual ventilation during the measurements, the mean emission rate remained the same, but the standard deviation was reduced considerably: from mean 19070 ou_E/hour with standard deviation 8000 ou_E/hour (42%) to mean 19840 ou_E/hour with standard deviation 1500 ou_E/hour (7.6%). This finding would suggest that the temporal variations in emission rate are mainly associated to ventilation rate, which is in turn determined mainly by the outside temperature.

This is a relevant observation when assessing nuisance potential, as annoyance is most likely to occur in summer conditions, when residents are likely to be outside in good weather. This situation would coincide with conditions requiring relatively high ventilation rates in the livestock unit, in turn associated with above average emission factors.

In earlier work, emission data were collected for the Ministry of Agriculture, Fisheries and Food in the United Kingdom between 1987-1995[34]. The olfactometry used at the time was compatible with the Dutch NVN2820 standard method, and used an n-butanol reference value of 20 ppb/v. To convert its findings to European Odour Units, a conversion was applied on that basis: 1 ou_E/m^3 = 2 ou/m^3. The measurements for this study were mainly carried out in the winter of 1993 (November 1992 to March 1993). As can be seen from the Belgian results in Table 12 this may have caused a bias towards lower values, by as much as a factor two. The report by ADAS proposes emission rates 'for inventory and planning purposes' that are listed in Table 13, including conversion to European odour units and expressed for a typical weight of a fattener of 85 kg. The suggested emission rate for a fattener of 18.7 ou_E/s is not significantly different from the results found in the Netherlands (22.4 ou_E/s) and Belgium (25.4 ou_E/s), especially when considering the potential 'winter bias' in the UK data mentioned before. The limited measurements that were carried out on two Irish pig production units, reported in Part B of this report, provided values between 7.3 and 20.2 ou_E/s for fatteners, measured in winter conditions. These data, with a geometric mean of 13.2 ou_E/s and a median value of 15 ou_E/s per fattener, fit well within the range of data as found in the Belgian study, for winter conditions, with a geometric mean of 15.4 ou_E/s. The data from the three studies abroad and the data measured in Ireland for this study broadly support the recommended value for the emission of fatteners for impact assessment in Ireland of 22.5 ou_E/s.

Table 11: Emission factors for distinct categories of pigs held in conventional and low emission livestock housing in the Netherlands, measured from 1996-1999. Each cell is based on 20 observations in both summer and winter.

Live stage of animal	Housing type code	Emission rate per animal	Coefficient of variation	Minimum	Maximum
			ou_E/s	ou_E/s	ou_E/s
Fatteners, conventional, partially slatted	FP-C	22.4	57%	8	85
Fatteners, restricted emitting area below slats	FP-L1	9.6	25%	7	15
Fatteners, cooling of slurry surface below slats	FP-L2	10.8	36%	6	18
Fatteners, flushing twice/day below slats	FP-L3	10.9	49%	5	23
Weaners, conventional, fully slatted, first sampling run	WP-C	16.3	53%	8	35
Weaners, conventional, fully slatted, second sampling run	WP-C	5	79%	1	11
Weaners, restricted emitting area	WP-L	4	140%	1	16
Farrowers, conventional, fully slatted	FS-C	17.8	47%	7	35
Dry sows, conventional	DS-C	19.0	47%	8	37
Dry sows, group housing with feeding station	DS-L	6.8	69%	3	19

Source: Ogink, N.W.M., Groot Koerkamp, P.W.G., 2001[10]

Table 12: Emission factors from distinct categories of pigs measured on one farm in Bierbeek, Belgium. Each cell is based on 20 observations in both summer and winter.

Pig category	Annual	s.d	Summer	s.d	Winter	s.d.
	ou_E/s		ou_E/s		ou_E/s	
Fatteners, total	25.4	22.5	32.7	27.1	15.4	9.3
Fatteners, cell C5	26.4	24.8	34.4	29.9	15.4	8.5
Fatteners, cell C6	24.4	20.8	31.2	24.4	15.4	10.5
Weaners	3.3	1.8	3.8	2.1	2.8	1.4
Farrowers	17.2	11.2	20.1	13.1	14.5	8.5
Dry sows	44.6	32.2	52.6	36.2	34.8	25.2

Source: Van Langenhove, H., De Bruyn, G, 2001[32]

Table 13: Emission factors for planning purposes, as proposed by ADAS, UK, 1995, with conversion to European odour units.

	Emission factor	Emission factor	Weight animal	Emission animal
	$ou.kg^{-1}.s^{-1}$	$ou_E.kg^{-1}.s^{-1}$	kg	$ou_E.s^{-1}$
Finishers, fully slatted, mean value	0.85	0.43	85	36.1
Finishers, fully slatted, maximum value	3.00	1.50	85	127.5
Finishers, part slatted, mean value	0.44	0.22	85	18.7
Finishers, part slatted, maximum value	1.10	0.55	85	46.8
Finishers, straw bed scraped	0.47	0.24	85	20.0
Finishers, straw bed scraped	1.25	0.63	85	53.1

Source: Peirson, S, Nicholson, R., MAFF Project WA0601 - Measurement of odour and ammonia emissions from livestock buildings Phase 1 final report. ADAS, Cambridge, United Kingdom, March 1995.

After conversion of the UK results to European odour units (1 $ou_E \cdot m^{-3}$ = 2 $ge \cdot m^{-3}$) the mean emission factors from the UK study are in the order of 0.43 $ou_E \cdot s^{-1} \cdot kg^{-1}$ for a fattener on a fully slatted system and 0.22 $ou_E \cdot s^{-1} \cdot kg^{-1}$ for a part slatted system. These values correspond with Dutch data presented in Table 11 that are equivalent to specific emission rate for fatteners of 85 kg live weight on a part slatted system of 0.26 $ou_E \cdot s^{-1} \cdot kg^{-1}$. Limited measurements on an Irish pig unit, presented in Part B of the report of this study, arrived at a (geometric) mean specific emission rate of 0.22 $ou_E \cdot s^{-1} \cdot kg^{-1}$ for fatteners.

As the differences between measured emissions per animal from different sources are not clearly significant, given the observed variation of emission rates measured on different days within one pig unit and between pig units, the data presented in Table 10 provide the best estimate for emission rates currently available.

8.6 Cumulation

In the Irish situation, cumulative impact of large numbers of sources affecting the same receptor site is relatively rare. It has been found that even in situations where cumulated exposure from multiple pig production units occurs, the impact in terms of percentage of people annoyed can be adequately predicted on the basis of the calculated exposure caused by the one dominant source only[4]. Therefore, in order to simplify the assessment, only the predominant source is to be used in assessment of impact.

The predominant source is defined as the source with the largest proportional contribution to the odour impact ($C_{98,\ 1\text{-hour}}$) at the receptor location in question.

8.7 Practical application of the assessment framework

The assessment framework provides for a simplified assessment method for cases in which it can be reasonably expected that the underlying environmental quality criteria will be met. Those cases can be assessed using a simple screening method, employing map overlays with standard contours. The aim is to reduce the burden of assessment where this is feasible, with reasonable confidence.

In those cases where the answer to the question: *Are the environmental quality targets for odour attained?* is not easily answered with an unequivocal Yes, a more detailed assessment route must be followed. The detailed assessment involves making a best estimate of odour emissions, on the basis of the number of animals present at the facility at full design capacity and a schedule of emission factors per animal, differentiated to the stages in the life cycle of the pig. These factors can take low-emission practices into account, when relevant emission factors are available or abatement efficiency can be reliably estimated.

Only in those cases where the applicant asserts that lower emission factors than those listed in this document are applicable, will measurements of emissions per animal on site be required. The statistical design of the sampling programme must be suitable, in that case, to yield statistically significant conclusions on differences with the standard emission factors.

Contours can be calculated, using the estimated emissions and a suitable atmospheric dispersion model, which uses the topographical and meteorological data applicable to the specific site, and drawn on the map of the vicinity to represent the environmental quality targets that have been set as the basis for this assessment framework. Comparing the location of odour sensitive receptors, such as residential dwellings, relative to these contours, will provide the licensing officer with the framework for setting licensing conditions.

The assessment process for licensing, where odour exposure is involved, has been outlined in Figure 6. This approach to assessment has been illustrated in three case studies, see Chapter 10.

Framework for Assessment of Odour Impact in EPA Licensing

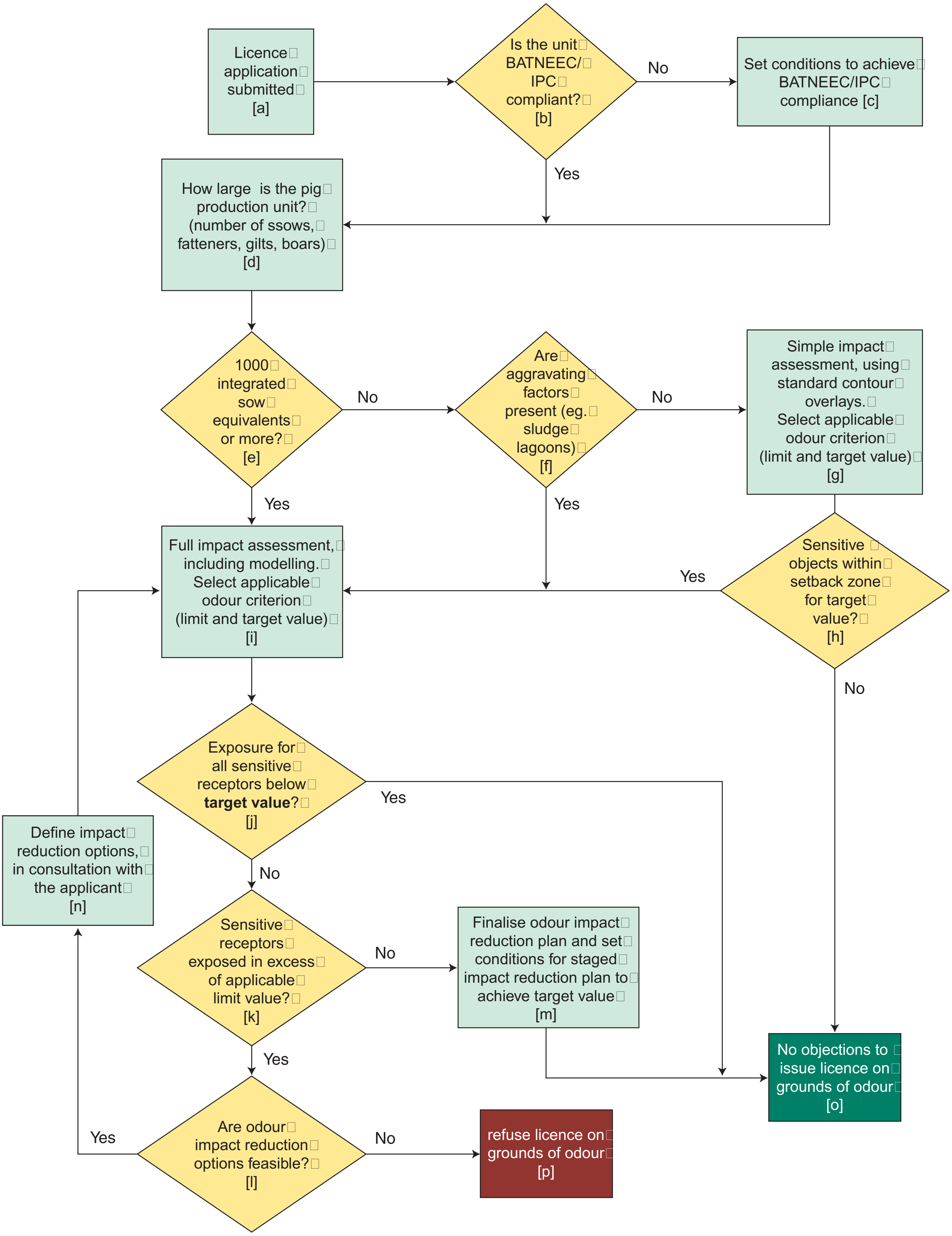


Figure 6: Odour Impact Assessment framework flowchart

8.8 The general, simple case: assessment by screening using standard contour overlays

To make a first assessment, figures with standard contours for integrated units have been produced, which are included in Annex E of this report. These contours represent a simple case, for flat terrain, for an inland meteorological station (Claremorris). By copying these standard contours on an overhead sheet, at the scale appropriate for the topographical map of the vicinity, a quick assessment can be made, aimed at establishing whether the pig production unit involved is well clear of potentially causing a nuisance. If that is the case, the assessment for the application does not need to go any further.

In the event that the outcome is either 'borderline' or indicates that sensitive receptors are within the standard contours, a more detailed assessment is to be made.

The relevant figures can be found in Annex E:

- Figure 16 Standard contour overlay, representing typical contours for the target value for all pig production units of $C_{98,\ 1\text{-hour}} = 1.5\ ou_E/m^3$, for integrated sow units of different sizes, scale 1:50,000.
- Figure 15 Standard contour overlay, representing typical contours for the limit value for new pig production units of $C_{98,\ 1\text{-hour}} = 3\ ou_E/m^3$, for integrated sow units of different sizes, scale 1:50,000.
- Figure 17 Standard contour overlay, representing typical contours for the limit value for existing pig production units of $C_{98,\ 1\text{-hour}} = 6\ ou_E/m^3$, for integrated sow units of different sizes, scale 1:10,560.

The contours can be a-symmetrical to some degree, reflecting the predominant SW wind directions in combination with wind velocity and stability of the atmosphere in Ireland. The setback distances can, as a result, be dependent on the location of the sensitive receptor relative to the source.

The standard contours were calculated using meteorological data for Claremorris, for the years 1993 to 1995 (inclusive). The terrain was assumed to be perfectly flat for the purpose of the calculation of standard contour lines for screening purposes.

The protocol for the simple assessment using standard contour overlays is summarised below:

1. Determine which criterion is applicable
2. Select the appropriate overlay figure
3. Copy to the standard contour figure on an overhead sheet at the correct scale for the underlying topographical map, on which the locations of the sensitive receptors are marked
4. Determine the size of the pig production unit of the applicant. Choose the contour for the nearest higher number of sows: this is the appropriate standard contour
5. Place the overlay on the topographical map, with the centre cross in the centre of the pig production unit
6. Assess if any sensitive receptors are located within the appropriate standard contour. If that is the case, carry out a full impact assessment.
7. If no sensitive receptors are located within the appropriate standard contour, the licence can be approved, as far as odour impact is concerned, as long as BATNEEC conditions are applied.

The standard contours provide a reasonable indication of the impacted area, but specific factors, such as local topography and meteorology and configuration of emission points may have a significant impact on the actual shape and location of the contours for the specific study site. Where the final decision hinges on detailed location of contours, actual modelling is advisable, particularly if the consequences of the decision are potentially large.

In making impact assessments all relevant local information should be considered and its implications for the impact of the odour exposure on the nuisance potential should be taken into account.

8.9 Full impact assessment using atmospheric modelling

To carry out a full impact assessment, a modelling study needs to be carried out, using a suitable atmospheric dispersion model to determine the contours on the map where a chosen exposure criterion occurs (e.g. $C_{98,\ 1\text{-hour}} = 3\ ou_E/m^3$).

The outcome of the model depends entirely on the data input. It is important to collect adequate data for model input. This requires a balanced approach. Too little detail may, therefore, lead to unreliable results, while too much detail may require an inappropriate amount of resources to collect, perhaps wrongly suggesting an accuracy for the prediction that is unrealistic relative to the inherent uncertainties in the model.

The typical data required are:

- *Source characterisation data*, describing the location, flow characteristics and emission rates of the source;
- Terrain data, describing the topography of the study area, and characterising the 'terrain roughness, or the typical size of obstacles as far as these affect the turbulence in the boundary layer of the atmosphere;
- *Meteorological data*, for a minimum of 3 years, consisting of a continuous set of hourly observations for wind direction, wind speed and 'stability class', a parameter describing the turbulence in the boundary layer.

The collection of those data is described below. Before modelling, a decision must be made as to which exposure criterion is to be applied to the production unit under study. Then the following data need to be collected:

1) Source characterisation:

a) *Prepare an inventory of the location*, dimensions and height of the production units (buildings, storage facilities, ventilation points, air treatment units, etc.)

This inventory can be done on a detailed scale, locating individual ventilation shafts, their location, capacity, mean regulated rate, etc. However, this level of detail will, generally speaking, not be required. The larger the distance to the sensitive receptor, the less detail is required. At a distance of 100 m, the location of a ventilator may have an effect, which is likely to be irrelevant at a distance of 800 m. A simplified method, dividing the area of buildings into areas (or pixels) of no more than approximately 20 m x 20 m, each represented by one point source, will provide sufficient detail for the impact assessment at distances of approximately 200 m and more from the source.

b) *Determine the emission per building*, on the basis of the housing capacity and the type of animals housed in that building. Using the emission factors, listed in table Table 11, the emission for that housing unit can be determined, and assigned to as many point sources as is deemed necessary to represent the emission adequately for the purpose of modelling. The ventilation flow rate, the height of the emission point, the exit velocity and the diameter of the exit duct must be estimated based on the actual conditions and the number of animals represented by the area chosen. As odour annoyance is most likely to occur in summer, when residents are outside, or have windows open, the exit velocity based on summer ventilation rates are arguably the most relevant to use in modelling. For establishing the worst case, winter ventilation rates should be used to establish input for dispersion modelling. Some models accommodate different sets of sources to be entered as input for each season, or even per month, which is the most accurate approach.

2) Characterisation of terrain in the vicinity

a) *Topography.*

To calculate a contour for an exposure criterion, e.g. $C_{98,\ 1\text{-hour}} = 3\ ou_E/m^3$, a grid of receptor points is required. The model will calculate exposure for each point on the grid, and then use a suitable interpolation method to draw a continuous contour line. Specific receptor locations on the grid may be entered, representing the location of defined sensitive receptors, for detailed consideration. In setting up a grid, the following considerations apply.

A finer grid causes significantly longer runtimes for the modelling software. A coarser grid increases the risk of errors induced by the interpolation to draw contour lines. At distances up to 300 m a grid with a grid step of 50 m is advisable. Between 300 m and 1000 m a grid step of 100 m is recommended. Between 100 m and 2000 m a grid step of 250 m is required. At larger distances a grid step of 500 m may be used. Slight topographical features, such as elevation differences of 5 m or less, within the first 300-400 m or 10 m or less at distances greater than 300 m are not very relevant for the model results in most cases, except those that are borderline relative to compliance with the selected criterion for the site.

i) If topography is not an issue, a grid of receptor at the same elevation as the source can be used.

ii) If topography is an issue, than an actual elevation must be added to each point on the receptor grid. Elevation can be obtained from maps, preferably directly in digital format.

b) *Terrain roughness.*

Terrain roughness is a parameter with the unit metre [m] that is used to characterise mechanical turbulence in the lowest part of the mixing layer, just above the earth surface. The parameter is determined on the basis of the size of obstacles, using the following scale:

i) 0.03 m - plain surface with only low vegetation (grassland) with only occasional small obstacles, e.g. airfields, plain meadows or field after ploughing.

ii) 0.10 m - Fields with regular cover of low crops, or grasslands with drainage ditches no more than 20m apart. Occasional minor obstacles can occur at distances in excess of 20 times their height, such as low windrows, single lines of trees without leaves, individual farm buildings.

iii) 0.25 m - Fields with intermittently high and low crops. Larger scale obstacles (e.g. rows of trees with leaves, low orchards) occur at distances of more than 15 times their height.

iv) 0.50 m - Larger obstacles (e.g. larger farm buildings, wooded areas) occur at distances of approximately 10 times their height, separated by shrubs, new forest with young trees and mature orchards.

v) 1.0 m - Area regularly covered by larger obstacles, at distances not exceeding a few times the height of these obstacles, e.g. mature forest, low to medium density residential areas in villages and towns.

vi) 3.0 m - Cityscape with intermittent low, single and double storey, and higher multi-storey buildings. Can also apply to woods with very high trees and many, irregular openings.

3) *Meteorological data*

A minimum of 3 years of continuous meteorological observations is required, giving hourly observations of wind speed, wind direction and stability class (see also section 5.3.3).

8.10 Specific terms and definitions

- *Distance to source.* The distance between the off-site receptor point, such as the closest elevation of a corner of a residence, and the nearest emission point (ventilation shaft or natural opening).

9. Methods for reduction of odour impact

9.1 What causes odourants to be produced?

The odours generated in a pig production unit originate from:

- Feed
- Spilled feed
- Body odour of the animals
- Urine and faeces

The most relevant source of odourants from pig production is the excreta. As feed passes through the digestive tract, food is transformed into smaller molecular structures that can be adsorbed into the blood stream and used for growth and the energy need of the animal. The excess nutrients and those components that are not digested are excreted as urine and faeces. These can be collected either separately, or mixed in the form of slurry. The biological degradation process, that started in the digestive tract, under anaerobic conditions, continues after excretion.

There are two basic routes for biodegradation of pig manure or slurry: anaerobic (Figure 7) or aerobic processes. The aerobic process is faster, and produces less odourants, than the anaerobic process. Generally speaking, however, urine and faeces are collected in mixed form, and the resulting slurry is degraded in anaerobic conditions.

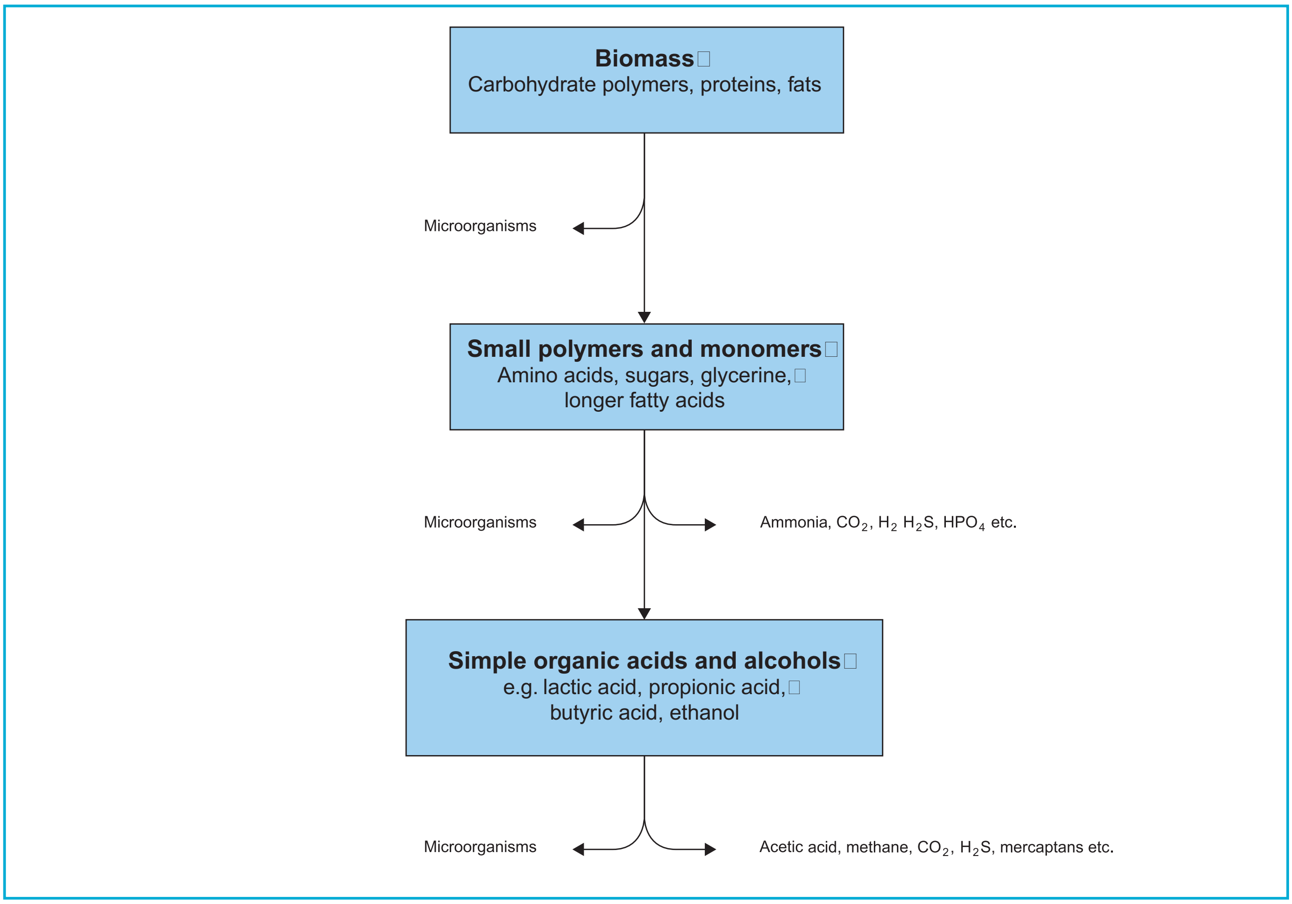


Figure 7: Anaerobic biogenic transformation, simplified

As a result of anaerobic biogenic transformation of organic matter and nutrients by mainly bacterial biomass, odourants are produced. The human sense of smell has evolved to be highly sensitive to these odourants. This is relevant to survival, as the ability to detect these odourants as smells is our main method for evaluating the chemistry of our environment and food. The common word for anaerobic degradation is rotting, and rotten food is a health threat. Our sense of smell has evolved specifically to detect by-products from rotting, as an immediate health warning. In particular the by-products of rotted proteins, a high-risk food, are easily detected: substances containing sulphur (e.g. H_2S and mercaptans, indicative of rotten eggs) and nitrogen (e.g. amines, indicative of rotten fish).

Odourants in pig slurry are mainly formed as a product of anaerobic metabolism that occurs when all dissolved oxygen has been depleted by bacterial respiration. The underlying metabolism is complex, and produces a wide range of chemical compounds, see Figure 7. Many are highly odorous, such as mercaptans, organic sulphides, amines, organic acids, aldehydes and ketones. A secondary effect of anaerobic metabolism is the lowering of pH due to the formation of organic acids. The rate of formation of odourants, being a biological process, depends on a number of factors, such as the dry solids content, availability of nutrients, availability of oxygen and, significantly, temperature.

The variety of odourants in pig odours is considerable and some of these odourants are very smelly indeed, even at low concentrations.

Between 100 and 200 odourants, have been identified in pig odours[28]. Detection thresholds can be as low as ppb or even ppt levels (10^{-9} to 10^{-12}). At least thirty of the identified compounds are highly odorous, having odour detection thresholds of less than 1 $\mu g.m^{-3}$, see Table 14. The most recent odour threshold for H_2S, measured by dynamic olfactometry, measured according to EN13725:1999, is 0.5 ppb, which is equivalent to 0.7 $\mu g/m^3$.

9.2 Theoretical options for reducing odour emissions from pig production

The odourants that are released from the operations of pig production are the result of anaerobic metabolism of microorganisms. This conversion starts in the digestive system of the pig, but accelerates within hours after excretion.

Table 14: Compounds with low odour detection thresholds found in pig slurry[28]. Note: odour thresholds from literature, typically not measured according to EN13725.

Range of detection threshold C_{od} [$\mu g \cdot m^{-3}$]	Compound
$C_{od} \leq 0.01$	Methanethiol
	2-propanethiol
	2-propene-1-thiol
	2,3-butanedione
$0.01 \leq C_{od} \leq 0.05$	Phenylacetic acid
	Ethanethiol
	4-methylphenol (p-cresol)
$0.05 \leq C_{od} \leq 0.1$	Hydrogen sulphide
	1-octene-3-one
$0.1 \leq C_{od} \leq 0.25$	Benzenethiol
	2,4-decadienal
	3-methylbutanoic acid
	2,6 dimethylphenol
	3-methylphenol
	2,4-nonadienal
	Dacanal
$0.25 \leq C_{od} \leq 0.5$	Trimethylamine
	Octanoic acid
	Nonanal
	Methylthiomethane
	Ethyldithioethane
	2-phenylethanol
	3-methylindole (skatole)
	Butanoic acid
	2-methylphenol
	2-butene-1-thiol
	2-nonenal
$0.5 \leq C_{od} \leq 1.0$	Indole
	Pentanoic acid
	Butanal

The basic principles for reducing odour emissions are:

1. *Reduction of odourant formation in slurry*

    a. *Separation of urine and faeces, followed by treatment.*
    When solids are separated, the liquid fraction can

be treated by aeration, reducing the production of highly odorous compounds. The aerated liquid can be used as flushing liquid to collect slurry more efficiently from the pig houses. Aeration and separation of the solid fraction also provides a benefit in reducing the odour impact from spreading.

b. *Lowering of temperature of stored slurry*
The relation between temperature and the anaerobic metabolic rate is exponential. A reduction of the slurry temperature from 20°C to 10°C causes a reduction to less than 50% of the emission rate at 20°C.

c. *Reduction of the protein content in feed*

d. *Collection of slurry in closed tanks, followed by anaerobic digestion.*
In this process the odourants that are produced can be destroyed by controlled incineration of the biogas. The digested slurry is significantly less odorous, which is a great benefit when spreading[29].

2. Reduction of transfer rate from the surface of slurry

a. *pH control*
The pH of the slurry can be used to manipulate the balance between soluble, ionised forms of odourants and less soluble, volatile forms. Regulating the pH of slurry to low pH values, pH ≤ 7, can effectively control the emission of ammonia from slurry. The effect on the transfer rate of other odourants is ambiguous. At lower pH values the organic fatty acids will be released more readily to the atmosphere. Active chemical control of pH is not a practical tool for odour control.

b. *Covering the surface*
i. Natural crusting,
ii. Floating biological covers (straw, fibre),
iii. Floating covers (plastic film, polystyrene panels or porous stone),
iv. Liquid additives (vegetable oils),
v. Air-filled plastic domes (over sludge storage lagoons).

3. *Reduction of exposed area of slurry, including storage, soiled surfaces, grids etc*

a. Different housing types, which include systems such as:
i. Green Label pig houses, designed for low ammonia emissions,
b. Frequent removal of slurry and storage in closed tanks.

4. *Extraction of ventilation air with treatment to reduce odour concentration*
a. bioscrubbers,
b. chemical scrubbers,
c. biofilters.

5. *Miscellaneous additives*

a. Feed additives,
b. Slurry additives.

The economics of installing the technology to abate odour emissions must be assessed before this technology can be imposed on existing pig unit operations.

9.3 Good operational practice

It is good operational practice to keep the pigs and the surfaces in and around buildings clean.

Pigs with manure on their skin will have a significantly increased odour emission, as the body heat of the animal will accelerate the release of odours significantly.

Every surface covered in manure will be a source of odour. Reducing the exposed area of manure induces a direct reduction in odour emissions.

Keeping a clean operation is a matter of combining good design with good operational practice.

Sources of odour in and around buildings include:

- Wet and manure-covered floors;
- Dirty pigs, with manure on their skin;
- Spilled feed;

- Improper storage and disposal of dead pigs;
- Deep underfloor manure storage pits, with long residence time;
- Dusty surfaces, that can capture and release odourants;
- Elevated temperatures in manure storage pits and in pig houses.

9.3.1 Slurry removal

Long storage times and large storage volumes increase the emissions of odourants. As a general principle, pig manure must be removed to adequate storage pits or be subjected to an appropriate treatment, including land spreading, as quickly as practicable. The current widespread use of deep tanks under fully slatted pig houses is not ideal from an odour management perspective.

9.3.2 Cleanliness

- Ensure that pigs remain clean;
- Clean surfaces and slats regularly;
- Clean pens and storage units regularly, both the floors and the structure, using adequate means such as high pressure water washers;
- Remove any stagnant water from surfaces.

9.4 Housing design

9.4.1 Standard housing systems

The majority of existing housing in Ireland is the traditional fully slatted system. The main source of emission in these houses is the surface of the underfloor slurry storage.

9.4.2 Low-emission housing systems

Low-emission housing systems have been developed, mainly with the objective to reduce ammonia emissions. Most systems will reduce odour emissions as well as ammonia emissions, roughly in equal measures. The main principles for reducing emissions to air from pig housing are:

1. Limiting the exposed area of stored manure;
2. Frequent removal of manure by a sewage system;
3. Cooling manure, lowering the temperature of stored manure;
4. Faster discharge of the manure from slats, by using triangular iron bars, which are easily cleaned;
5. Frequent removal of manure by flushing or scraping.

A variety of systems have been developed, using these principles. In the Netherlands strong incentives have been made available to those implementing low ammonia emission systems. This has resulted in a relatively widespread application of a number of systems. These systems are described in detail in a document[30] that is publicly available on the Internet, at http://www.infomil.nl/lucht/index.htm:

Hendriks, HJM, van de Weerdhof, AM, *Dutch notes on BAT for pig and poultry intensive livestock farming*, Ministry of Housing, Public Planning and the Environment and the Ministry of Agriculture, Nature Management and Fisheries, August1999.

The main characteristics, including extra investment cost relative to constructing a fully slatted system, and the suitability to retrofitting existing buildings, have been summarised in Table 15.

Separate detailed studies for each of these housing systems are available or will become available under the so-called Green Label certification system. The detailed reports include measured emission rates for odours for each housing type.

Table 15: Low-emission housing systems, extra investment costs, operational costs and effectiveness for ammonia reduction.

Housing type	Animal	NH_3 emission	NH_3 reduction relative to, fully place slatted	Extra investment	Extra costs, annual, per pig place	Extra energy use per place	No animals housed in system, NL, 1999	Suitable for retrofit?	Reference in draft BAT document…
		[kg/place/ year]	[%]	[€]	[€]	[kWh/ year]			
Pen manure channel with slanted side wall(s), partly slatted floor, concrete slats	finishers	1.2	60%	3	0.50	0	5,000	most existing houses can be adapted	b, section 3.1.1
Pen manure channel with slanted side wall(s), partly triangular iron bar slatted floor	finishers	1.0	67%	23	15.00		250,000	depending on, existing pit design	section 3.1.2
Manure surface cooling channel, concrete slats	finishers	1.5	50%	30	5.50	14	20,000	yes	b, section 3.1.3
Manure surface cooling channel, triangular iron bars	finishers	1.2	60%	43	8.00	14	200,000	yes	b, section 3.1.4
Manure channel with gutters, partly slatted floor with concrete slats	finishers	1.2	60%	59	9.45	1.5		depending on existing pit design	b.section 3.1.5
Manure channel with gutters, partly slatted floor with triangular iron slats	finishers	1.0	67%	79	12.50	1.5	50,000	depending on existing pit design	b,section 3.1.6
Partly slatted or convex floor with plastic or iron slats	weaners	0.34	43%	-	-	0	1,000,000	depending on existing pit design	b, section 4.1.1
Shallow manure pit with a channel for spoiled drinking water	weaners	0.26	57%	6	0.45		250,000	depending on existing pit design	b, section 4.1.2
Pen manure channel with side wall(s) on a slope, partly slatted floor, triangular iron bars	weaners	0.17	72%	5	0.75		50,000	most existing houses can be adapted	b, section 4.1.3
Manure scraper under the slats	weaners	0.18	70%	69	12.30		40,000	no	b, section 4.1.4
Manure channel with gutters, partly slatted floor with triangular iron slatsexi	weaners	0.21	65%	25	4.15		75,000	depending on sting pit design	b, section 4.1.5
Manure surface cooling channel, triangular iron bars	weaners	0.21	65%	24	4.40		150,000	yes	b, section 4.1.6

(Source: Dutch notes on BAT for Pig- and Poultry intensive livestock farming, draft, August 1999

Table 15: Low-emission housing systems, extra investment costs, operational costs and effectiveness for ammonia reduction. (continued)

Housing type	Animal	NH_3 emission	NH_3 reduction relative to, fully place slatted	Extra investment	Extra costs, annual, per pig place	Extra energy use per place	No animals housed in system, NL, 1999	Suitable for retrofit?	Reference in draft BAT document…
		[kg/place/ year]	[%]	[€]	[€]	[kWh/ year]			
Board on a slope under the slatted floor	farrowers	5.0	40%	260	29.50		few	yes	b, section 5.1.1
Manure surface cooling channel	farrowers	2.4	71%	302	54.25		10,000	yes	b, section 5.1.2
Combination of a water- and manure channel	farrowers	4.0	52%	60	1.00		50,000	yes	b, section 5.1.3
Manure pan	farrowers	2.9	65%	280	45.85		10,000	yes	b, section 5.1.4
Manure scraper	farrowers	4.0	52%	785	147.20		1,000	sometimes, depending on existing pit design	b,section 5.1.5
Flushing system with manure gutters	farrowers	4.0	52%	535	86.00	8.5	500	depending on existing pit design	b, section 5.1.6
Small manure pit	dry sows	2.4	43%	18	5.80		1,500	depending on existing pit design	b, section 6.1.1
Flushing gutters	dry sows	2.5	40%	162	57.90		1,000	depending on existing pit design	b, section 6.1.2
Manure surface cooling channel triangular iron bars	dry sows	2.2	48%	113	20.35	8.5	3,000	yes	b, section 6.1.3

(Source: Dutch notes on BAT for Pig- and Poultry intensive livestock farming, draft, August 1999

9.5 Optimisation of ventilation and atmospheric dilution

9.5.1 Ventilation in livestock housing

The ventilation rate in a pig production unit is determined by the needs of the animals. Adequate ventilation is vital, to perform the following functions:

- *Regulate temperature*
  Pigs produce a significant quantity of energy, in the form of heat. The excess heat is removed from the pig houses with the ventilation air, so that the temperature remains within the optimum temperature range, which varies for different stages of the pig life cycle. Too high temperatures cause growth rates to slow down, while low temperatures increase the risk of disease and cause a lower feed conversion efficiency.

- *Remove excess carbon dioxide (and ammonia etc.)*
  Due to the high density of biomass in pig houses, ventilation needs to be carefully regulated to remove the CO_2 produced by the respiration of the animals. CO_2 levels are kept below 3%.

Because of the importance of ventilation rates for pig welfare and productivity, ventilation rates cannot be easily modified.

Ventilation rates vary with the seasons. In summer, the main determining factor is temperature control, while in winter the CO_2 concentration may become the main determining parameter for the ventilation rate.

The ventilation rates in spring, summer and autumn are the most relevant for the odour impact, as these are the seasons where exposure in the vicinity of the facility is most likely to cause annoyance. As odour annoyance is most likely to occur in summer, when residents are outside, or have windows open, the exit velocity based on summer ventilation rates are arguably the most relevant to use in modelling. For establishing the worst case, winter ventilation rates should be used to establish input for dispersion modelling. Some models would accommodate inputting different sets of sources for each season, or even per month, which is the most accurate approach.

9.5.2 Optimisation of atmospheric dilution

9.5.2.1 Increase of emission height

Increasing the height at which the odorous emissions are released into the atmosphere can be a relatively economic and effective method to reduce the impact.

For a mechanically ventilated pig house with a number of ventilators, raising the emission point to 4 or 5 metre above the roof will limit the ‘building wake effect’ and hence enhance dilution downwind. This is especially noticeable at relatively short distances from the source (up to 300 m). To optimise dispersion of odours in the atmosphere, apex ventilators, especially those with appropriate ducting aimed at lifting the emission point above the roof, are preferable over side wall ventilators

More significant benefits can be obtained when the ventilation flow is ducted to a central stack. By increasing the stack height to between 10 m and 25 m, a marked benefit is achieved in terms of downwind dilution. The extent of this beneficial effect should be determined for each situation on the basis of dispersion modelling. The point of maximum concentration at ground level will move away from the source when raising the height of the emission point, which is generally a benefit, but in some cases may cause an increase of exposure for specific receptors.

In Figure 8 the effect of raising the emission height is illustrated, for a typical emission for an integrated sow unit of 670 sows, with:

- Natural ventilation or ventilation at roof level (4m);
- Mechanical ventilation, exit velocity 5 m/s, at 4 m above roof level (8m);
- Mechanical ventilation, emission through stack at 15 m, exit velocity 5 m/s;
- Mechanical ventilation, emission through stack at 15 m, exit velocity 15 m/s.

9.5.2.2 Increase of emission velocity

Optimising the vertical velocity of the emission helps ‘plume rise’ to occur due to the momentum of the ventilation flow. This increases the effective emission height, which benefits the dilution downwind. Optimum exit velocities are in the range of 10-15 m/s.

The effect of optimising the way in which emissions are released into the atmosphere is illustrated in Figure 8 below.

9.5.2.3 Vegetation and landscaping

The use of barriers and earth screens and/or vegetation is strictly speaking not an odour abatement technology. The adsorption of airborne contaminants to foliage is generally very low to the point of insignificance, with the possible exception of ammonia.

The effect on dispersion can be either favourable or unfavourable. In the wake of obstructions in the flow, an area of uniform mixing occurs that can either reduce or increase concentrations at receptor level, depending on the actual site configuration. As a rule the benefits are not clear, and this should not be relied upon as an odour abatement method.

As odour annoyance is ultimately a cognitive psychological process, however, landscaping and visual impact will have an effect on the appreciation of the odour. When the source is not visible, or obscured by pleasant vegetation, the odour may be appreciated as less negative than the same odour emanating from a secretive production unit behind a forbidding fence, with signs saying DANGER - KEEP OUT.

The visual impact of a site is the starting point of community relations and should be considered as such.

9.6 Feed

A high protein diet increases the availability of nitrogen and sulphur in the manure. These substances are the precursors to very odorous substances when the anaerobic digestion of that manure occurs. From the odour reduction perspective, it is, therefore, advisable to reduce crude protein levels, while providing the essential amino acids in adequate amounts to ensure optimum growth.

The benefits in odour emissions per animal are relatively poorly documented so far, but indications are that a reduction in odour emission is not likely to be greater than 50%, and more likely to be in the order of 25-30%[31].

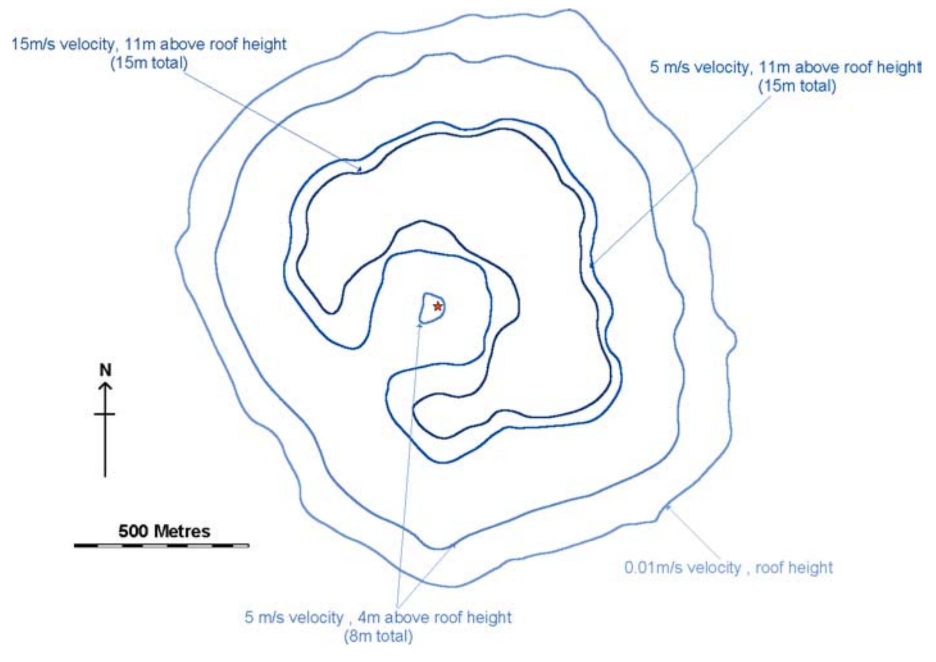


Figure 8 Odour contours for for a fictitious pig unit with a) natural ventilation at roof height, b) mechanical ventilation 4m above roof apex, exit velocity 5 m/s, c) all emissions through stack of 15m height, exits velocity 5 m/s, d) as c but velocity 15 m/s. Meteorological data for Claremorris.

9.7 Additives

9.7.1 Feed additives

Many feed additives have been introduced to the market in recent years, and a number of producers claim benefits in terms of reduced emissions of odourants as a result.

Additives include:

1. *Fats and oils*. By reducing feed dust generation, the release of dust-bound odourants can be reduced.

2. *Absorbing additives,* e.g. calcium bentonite, zeolite and activated charcoal. These substances are added with the objective to absorb odourants to counteract their release from the manure.

3. *Plant extracts.* A natural extract from the yucca plant, sarsaponin, has been reported to reduce ammonia emissions. No significant effect on odourant releases has been confirmed, however.

4. *Enzymes*.

5. *Microbial formulae*.

9.7.2 Slurry additives

Slurry additives are available in a wide variety of products. The main generic types are reviewed in the following sections.

9.7.3 Odour counteractants and masking agents

Masking agents and counteractants are gas phase treatment methods, in which an odour treatment agent is mixed directly with the foul airflow, usually by atomising a liquid using sprays. This may be done in ducts but also after release of the odourants into the atmosphere, using open-air sprays.

- *Masking agents* are odourants with a relatively pleasant odour, that are used to mix with the foul air to produce a more acceptable mixed odour or even ‘drown out’ or overpower the foul odour with the masking odour. The resultant odour is inherently more intense than the original odour, but arguably the character of the odour becomes less offensive.

- *Counteractants* are agents that interfere with odourant molecules with the aim of reducing the odour intensity of the mixture, as well as making the character of the odour more acceptable. The underlying process is not specified, but a form of encapsulation on a molecular level is implied.

Masking agents may have a public relations benefit in the short-term, communicating that some short-term action has been undertaken in acute conflict situations. In the long-term they may be counterproductive, however, as the masking odour becomes associated with the cause of the annoyance. As the intensity of the masking odour is higher than that of the original odour, it will increase the magnitude of the problem, rather than reduce it.

Masking agents and counteractants are used fairly frequently to provide immediate relief.

There is a lack of quantitative data to quantify potential benefits of these techniques. A 1993 study for wastewater treatment odour abatement by the Water Research Centre in the UK did not demonstrate a significant difference between the effectiveness of a counteractant and water in reducing odours. Most performance evaluations are anecdotal.

9.8 Extraction and treatment of ventilation air

Once the air can be ducted to a central point for treatment there are a number of options for reducing the odour concentration in the exhaust air. A number of options have been listed here:

- Chemical scrubbing;

- Biological scrubbing;

- Biofiltration, potentially combined with pre-treatment for H_2S using a catalytic iron filter;

- Biofiltration on fixed medium substrate covered with a biofilm, such as a lava-rock filter.

These techniques all have the potential to reduce the odour concentration in the ventilation air significantly, with an efficiency of up to 90-95%. The techniques are well known, proven technologies in applications in other processes, e.g. wastewater treatment. The treated ventilation air could be released from a raised stack, to further reduce the odour impact by achieving atmospheric dilution.

The main disadvantage of this approach is cost. The quantities of ventilation air are considerable, and determined by the ventilation needs of the animals. For this study a ventilation rate of between 50 and 100 m^3/hour per fattening pig was used for estimating emission volume flow rates.

The cost and feasible abatement efficiency for the different systems that can be applied are summarised in Table 18. In reviewing the cost of abatement systems, the cost of ducting to collect the air and duct it to the treatment unit must be taken into account. As a rough budget estimate, ducting amounts to an investment of between €0.80 and €1.60 per m^3/hour ventilation capacity.

9.8.1 Chemical scrubbers

Chemical scrubbers are used as an end-of-pipe treatment, before the ventilation air is released into the atmosphere. Chemical treatment of air in scrubbers is a proven technology, which can achieve an odour abatement efficiency of 70-90%.

In a wet scrubber, foul air is vigorously mixed with a scrubbing liquid. Typically the airflow is counter-current (upwards) but crosscurrent is an option. Most systems are packed with random plastic media. Unpacked scrubbers rely on fine droplets (mist scrubbers) and usually require demisting. Scrubbers are essentially a chemical processing system and proper chemical engineering is required for successful application.

Wet scrubbing relies on mass transfer of (odorous) compounds from the gas phase to the liquid phase. Usually chemical scrubbing is applied, where chemicals are added to the scrubbing liquid that can react to transform odorous substances to ionised forms or decompose them to less odorous compounds by oxidation. Alkaline or acid scrubbers rely on the formation of salts. Oxidising scrubbers (e.g. chlorite, potassium permanganate, peroxide) will oxidise dissolved pollutants. Ozone can be used to react with pollutants both in the gas and the liquid phase. Catalysts can be used to make the chemical reactions in the scrubbing liquid more effective and reduce requirements for chemicals.

Single-stage acid scrubbers have been reviewed as a method for ammonia emissions reduction for the pig production sector in in the Netherlands[30], and were

Table 16: Budget cost (€) for different end-of-pipe treatment methods, per unit ventilation capacity.

Treatment method	Cost per m^3/hr ventilation capacity						Remarks
	Investment [€]		Operation [€]		Total [€]		
	From	To	From	To	From	To	
Single stage chemical scrubber	0.41	0.86	0.14	0.28	0.23	0.45	Designed for pig houses (Cost data from the Netherlands[30])
Bioscrubber	0.41	0.86	0.17	0.33	0.25	0.50	Designed for pig houses (Cost data from the Netherlands[30])
Biofilter	2.05		2.55		4.60	-	Industrial applications
Bioscrubber	3.55	6.33	3.27	15.92	6.82	22.25	Industrial applications
Two stage chemical scrubbing	1.87	1.87	10.82	27.40	12.68	29.27	Industrial applications
Dry scrubbing	3.70		4.03		7.73	9.27	industrial applications

Table 17: Indicative budget costs (€) of ammonia (and odour) abatement in ventilation air, using single-stage chemical scrubbers. (Netherlands, 1997) [30]

Abatement system	Cost per animal capacity (fatteners) When data are not stated in the reference, the table cell is left blank									Source	Remarks
	Capital investment [€]			Life	Capita cost [€]	Operational cost [€]			Total annual [€]		
	Abatement unit	Ducting etc	Total	Years	Total	Energy	Other	Total			
Single-stage capacity chemical scrubber	42	43.18	85.00	10	8.50	3.89	10.11	14.00	22.50	a	Optimal of a unit is for 2000 fatteners or equivalent
Single-stage chemical scrubber	43							14.00		b	fatteners
Single-stage chemical scrubber	9							3.00		b	weaners
Single-stage chemical scrubber	84							28.00		b	farrower
Single-stage chemical scrubber	63							25.05		b	farrower

found capable of reducing NH_3 emissions with efficiency up to 90%. The efficiency for odour removal[10] was found to be lower, at an average of 29%.

Diluted sulphuric acid is the most used scrubbing liquid in this system. Hydrochloric acid solutions may also be used.

A total commercial production capacity of approximately 2000 gestating sow places, 40,000 weaner places and 100,000 finisher places have been equipped with this system in commercial; application in the Netherlands (1999)[30].

The cost for single-stage chemical scrubbers is summarised in Table 17. Please note that these single-stage scrubbers were aimed at ammonia removal only. The cost of a multi-stage scrubbing system that is effective at removing odours may be significantly more costly, see Table 16

9.8.2 Bioscrubbers

Biological treatment of air in scrubbers is a proven technology, which can achieve an odour abatement efficiency of 70-80 %.

Bioscrubbers have been reviewed as a method for ammonia reduction in the Netherlands, and were found capable of reducing NH_3 emissions from 3.0-0.8 kg/animal capacity/year for finishers.

The technology is reasonably simple, and suitable for application in an agricultural environment. No chemicals are required, that might otherwise imply an additional environmental and Health & Safety risk factor.

The cost of bioscrubbers, as designed and applied specifically to pig production, seems to be relatively low (see Table 18), especially when compared to odour abatement systems used for industrial applications.

Table 18: Indicative budget costs (€) of odour abatement in ventilation air using bioscrubbers (Netherlands, 1997)

Abatement system	Cost per animal capacity (fatteners) When data are not stated in the reference, the table cell is left blank									Source	Remarks
	Capital investment [€]			Life	Capita cost [€]	Operational cost [€]			Total annual [€]		
	Abatement unit	Ducting etc	Total	Years	Total	Energy	Other	Total			
Bioscrubber	49	34.09	83.18	10	8.32	2.50	14.23	16.73	25.05	a	finishers
Bioscrubber	49			10				16.70		b	finishers
Bioscrubber	10			10				3.35			weaners
Bioscrubber	111			10				32.75			farrower
Bioscrubber	111			10				16.70			dry sows

Practical application has been identified in the Netherlands, for a capacity of in total approximately 1000 gestating sows, 20,000 weaners and 100,000 finisher places (1999)[30].

9.8.3 Biofilters

Biofilters are used widely for odour treatment, achieving abatement efficiencies from 70 to over 95%.

In a biofilter, a solid porous medium (e.g. compost) acts as a carrier matrix for a biomass of micro-organisms (e.g. bacteria, actinomycetes and fungi). The biologically active layer is moist, and the filter is kept at a high humidity. When an odorous airflow is passed through the filter bed, odorous compounds (gases, aerosols) that are soluble in water will be transferred to the water in the biologically active layer. The biomass will use these compounds for their aerobic metabolism, leading to biological oxidation of odourants to usually less odorous compounds.

Biofilters can be open or closed, can use upward or top-down flow and can contain any of a variety of media, such as mature stable compost, peat/heather, coconut shells, seaweed, tree bark, woodchips etc.

The medium layer is typically 1 m thick to avoid an unacceptable pressure drop. At airflows of typically 50-150 m^3/m^2/hour this implies that biofilters may require considerable areas of space.

Some suppliers market specific cultures of microorganisms. Typically, however, natural selection is behind establishing a specialist, well-adapted population in the filter to utilise the compounds in the airflow to their metabolic optimum.

Biofilters are typically used for treating medium to high volumes of odorous air, from 5000 m^3/hr to large flows of several hundreds of thousands m^3/hr, at low to medium odour concentrations
(5,000-100,000 ou_E/m^3).

Biofilters are most effective at temperatures between 15°C and 50°C. Air at higher temperatures cannot be treated. Cooling of warmer emissions may be required. The optimum temperature is between 25°C and 35°C. As the treatment rate depends on biological metabolism, the rate of treatment doubles with every 10 degrees, between 0°C and 40°C.

The foul air needs to have a high relative humidity to avoid drying out of the filter bed. Humidification of the incoming flow may be necessary. At high flows even a relatively small deficit in humidity may cause considerable mass loss of water in the biofilter bed. When the flow temperature increases in the filter, which is after all metabolically active and will produce some excess heat, the drying effect of the treated air may be exacerbated

The foul air needs to be relatively free of particles, as these may clog the medium. The foul air should not contain substances at concentrations that can have a toxic impact on the biomass.

Pre-treatment of the foul airflow may combine the removal of particles and the cooling and humidification of the flow before entering the biological treatment, using counter flow sprays.

The design of the humidification or irrigation system of the filter is crucial to its effective use. Irrigation can have multiple functions:

- *Moisture control*
  The primary function of irrigation is to keep the moisture content of the filter at the required level. The optimum moisture content may vary for different media.

- *Removal of metabolic products and pH control*
  In beds with, for example, a high H_2S loading, the pH in the filter tends to come down to very low values. The effectiveness of the filter is reduced, as a result. The optimum pH is between pH=6 and pH=8. Irrigation can help to remove acids to the drain. Some materials are more suitable to be irrigated in this manner (e.g. tree bark is suitable, while peat will tend to become soggy and lose its structure).

- *Nutrient supply*
  If the loading of the filter is very low additional nutrients may be required to maintain sufficient biomass. Surface water can be considered for this purpose.

Irrigation is best provided by an array of nozzles, with an even distribution over the surface of the bed. Dry patches should be avoided, as these may cause irreversible loss of effectiveness locally.

Biofilters typically have a distinctive residual odour, which will not be far below 100-300 ou_E/m^3. However, this residual odour will in most cases resemble the odour of the soil, which is an earthy odour generally not recognised as annoying, as its character resembles that of odours naturally emitted from soil.

9.8.4 Ozone treatment of ventilation air

Treatment of air using ozone is applied in feed production as an end-of-pipe odour treatment method. Practical application in pig production is rare.

Ozone is a highly reactive oxidising gas that can break down odourants to less odorous oxidised forms.

The working principle is that odourants in the foul air are mixed with air containing the treatment agent. In the case of UV treatment, ultraviolet radiation is used to ionise the oxygen in the foul air itself. The radicals that are formed, including ozone (O_3) will react with the odourants, oxidising these to less odorous compounds. The process depends mainly on turbulence (mixing), oxidant concentration and residence time. Residence time in the mixing chamber should be at least > 1 second, preferably as long as several seconds.

UV systems seem to be more effective when used to break down odourants with small molecular weight, such as H_2S, but less effective on larger molecules. Although manufacturers claim that the technology is suitable for large volume flows, residence time in the mixing chamber is difficult to maintain at the required length of one or more seconds.

Performance is claimed to be >90% for H_2S. It is known that efficiency is reduced for odourants with increasing molecular mass. Little information is available for such odourants, but indicative data would point to abatement efficiencies around 50%.

- *Strengths*
  - Low capital cost;
  - Suitable for on/off operation.

- *Weaknesses*
  - Odour abatement efficiency for odourants with higher molecular mass remains questionable.

9.9 Slurry storage

Slurry storage can be a highly significant source in terms of odour annoyance potential. Under anaerobic conditions, high concentrations of odourants can be formed in slurry, which can be released in highly concentrated ‘puffs’ when slurry is being handled. Turbulence, resulting from ‘stirring’ and pumping, can increase the emissions from the surface by an order of magnitude (factor 10) compared to a still surface.

On the other hand, natural crust formation can reduce the emissions from the surface significantly.

In assessing the relevance of slurry storage for odour annoyance potential it helps to realise that odour concentrations over slurry, or in headspaces, can reach tens or even hundreds of thousands of ou_E/m^3, whereas the odour concentration in pig house ventilation air rarely exceeds 5,000 ou_E/m^3. Small volumes of very strong odours can, under unfavourable circumstances, travel quite far and cause a strong odour intensity to be perceived by persons downwind. As this perception can be of high intensity, this can trigger annoyance and exacerbate nuisance.

It is therefore a significant area of interest to assess *slurry storage* and *handling for transport* as an area of opportunity for minimising odour impacts.

9.9.1 Odour emission reduction in open slurry storage

In many cases, slurry is stored in open tanks. In Ireland, storage underneath the fully slatted floors is common. Extra storage in the open air is becoming more of an issue lately. This is typically achieved in open to tanks or lagoons, built from foil, glass coated metal or concrete.

To reduce emissions from open, uncovered tanks, the following factors and approaches are relevant:

- Reduce the surface area to volume ratio (deeper tanks, rather than a larger area);
- Minimise turbulence, by careful design of tubing. All filling should occur under the liquid surface to avoid turbulence;
- If possible, formation of a natural crust should be encouraged;
- Treatment of sludge by mechanical separation or digestion or aeration can drastically reduce content of odourants, and hence the odour emission;
- Temporary cover such as straw, in a 10-20 cm layer, has been suggested as an effective method for reducing emissions from the surface;
- Reduce area of liquid exposed to air, using temporary or floating covers (e.g. polystyrene floating panels). These can reduce emissions significantly. Ammonia emission reductions of 70-80% have been reported.

9.9.2 Enclosed slurry storage

There are a number of options for enclosed slurry storage. This has a direct advantage in stopping almost all emissions to atmosphere. In rigid tanks, however, great care should be taken that highly odorous air from the headspace is not released in a ‘puff’ when loading or unloading. The headspace from tanker and tank can be attached, to form a closed system, or some form of odour control can be used. Enclosed tanks inherently form a potential Health & Safety risk, when incidental access is required, as they are likely to contain lethal concentrations of gases like H_2S.

Flexible solutions are becoming more popular, using methods of cover that avoid creation of headspace. An example of a covered storage without headspace are foil basins in an earth enclosure, with a floating foil cover. Floats support the cover, and an extraction system for escaping digestion gas is provided in the design. They are made out of reinforced plastic (PVC) foil of 1 mm thick (see Figure 9). Stirring of the slurry is achieved through pumping slurry through a specially designed fixed tubing system. These fully enclosed foil basins have an economic lifespan of at least ten years. Hundreds if not thousands of these systems have been installed in the Netherlands, at commercial pig units. No precise cost data are available, but the supplier indicates that the investment cost is close to half the cost of a concrete storage tank of the same capacity. The foil liner will be viable for an economic life of 10-14 years.

A relatively new approach is the use of large ‘slurry cushions’, derived from military storage systems for fuel and water.

Existing open top tanks can be covered by add-on covers, typically made out of glass reinforced plastics. From Canada the use of inflatable domes has been reported, although few details are available as to the practical application of such systems.

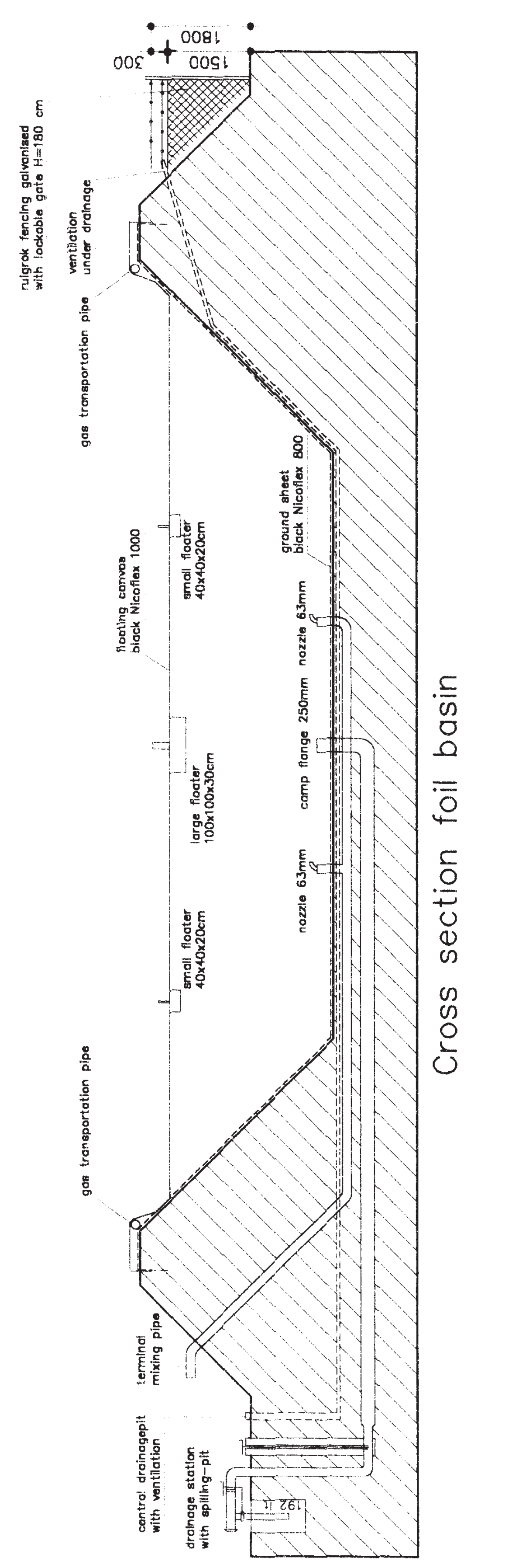


Figure 9 Fully enclosed slurry storage in earth shape with 1mm reinforced PVC lining (drawing courtesy of www.steenbergen.org)

9.9.3 Operational aspects of slurry storage

The following operational practices can be applied to reduce odour emissions from slurry storage:

- When the storage is not in use, clean the surfaces carefully. Even a few inches of anaerobic sludge at the bottom can be a significant source of odour emission;
- Avoid turbulence and splashing, as these can cause emissions from the surface to be increased by an order of magnitude;
- Always use pipes and tubes that extend to below the liquid surface when filling;
- Promote and preserve natural crust formation;
- Keep storage periods as brief as possible;
- Choose your moment for any sludge handling operation, so that the wind direction is favourable, winds moderate to high and the atmosphere turbulent.

10. Two case studies

In the course of this project two case studies were conducted for pig units in the Irish context. The case studies included odour emission measurements. For both locations dispersion modelling was used to assess the odour impact. Abatement options were considered to reduce the impact.

The case studies were conducted at two sites, and the characteristics are summarised below:

- A large integrated pig unit, with approximately 1000 sows in fully slatted pig houses;
- A medium sized integrated pig unit, with approximately 590 sows in fully slatted pig houses;

The case studies for the two sites listed above are reported in Part B of this report, titled: *Case studies assessing the odour emissions and impact of two pig production units in the Irish Situation* The measurements of odour emissions carried out at these two sites are also included in Part B.

For full details of the case studies, including a detailed report on odour emission measurements, please refer to Part B of this report, that is structured as a complete document. The essence of this report is provided below in an executive summary.

10.1 Executive summary Part B: *Case studies assessing the odour emissions and impact of two pig production units in the Irish Situation*

The Environmental Protection Agency has initiated a study into Odour Impacts and *Odour Emission Control Measures for Intensive Agriculture*, with the objective to assist the Agency in formulating its approach for processing the license applications with a view to achieving transparent and uniform decision-making.

In the course of this project, three case studies were conducted to assess the odour impact of pig production units in the Irish context. At two of these locations odour emission measurements were conducted. For all three cases dispersion modelling was used to assess the odour impact. Abatement options were considered to reduce the impact.

The objectives of these case studies were:

- To illustrate the approach as outlined the main Agency study *Odour Impacts and Odour Emission Control Measures for Intensive Agriculture*;
- To obtain a limited set of emission measurements for Irish conditions, to assess whether these are significantly different from the distribution of results found in the much larger data set from the Netherlands[5, 10].

It should be noted that the case studies were not intended to provide an overview representative for most Irish pig units. The scope of the case studies was too limited to do so. Similarly, the scale of the emission measurements was not sufficient to yield specific emission factors generally representative for Irish conditions.

The case studies prompted the following conclusions:

Conclusions on the results of finisher emission rate measurements in Ireland

The geometric mean emission rate of 13.2 ou_E/s per finisher measured in Ireland in winter conditions for this study is about one third lower than the value of 22.6 ou_E/s per finisher found in a larger study in the Netherlands[10].

Given the relatively small number of samples, collected in the Irish study, and the statistical variance as derived from the larger Dutch study, the difference in the mean outcome is too small to be statistically significant. Therefore, it is justified to use the emission factors derived in the Netherlands for emission estimates in Ireland, until emission factors specifically measured in Irish conditions are become available for a larger sample of study sites.

Odour impact study Farm A

Farm A is a large integrated unit, containing over 17 000 animals. It is therefore no surprise that total emissions are high, and the odour footprint relatively large. However, given the locality of the farm - its distance from residential units and its rural context, there seems to be no urgency as no complaints have been registered. The only concerns that were identified during the site visits were the uncovered slurry store and carcass skips. It is the opinion of Odournet UK that these sources may become a significant emitter of odours during the warm summer months. However, having undertaken sampling during a cool spring day, there is no quantitative data to support this.

The modelling shows that in the current situation a limited number of (five) dwellings may be affected by odour impacts in excess of the limit value. It is therefore necessary to seriously consider the need to reduce emissions and the options to do so. In the short-term measures to reduce emissions from sludge storage should be considered. In the longer term, replacement of housing assets could reduce the number of dwellings exposed to odour impacts in excess of the limit value, conceivably to zero. The target value will be difficult to attain for farm A. The farm can be made sustainable at current stock levels, from the perspective of odour impact, provided that the community recognises and accepts the rural context in the vicinity.

Odour impact study Farm B

Farm B is a relatively small-scale operation. Under current circumstances, the odour footprint does not include any domestic dwellings within the limit value contour. This farm does not require the installation of any abatement options if current stock numbers and good practice are maintained.

In the long-term, a reduction of odour emissions should be considered when normal renewal of housing assets becomes an issue. This could achieve attainment of the target value for all dwellings in the vicinity, or create room for some growth of stock when the agricultural context of the area is recognised and accepted as the status quo.

11. Conclusions

This report does not aim to provide one answer to a well-defined question, with a concise set of conclusions. Rather, it aims to provide the information, required by the Environmental Protection Agency, for defining a framework for answering the complex questions that need to be addressed to achieve a systematic and transparent IPC licensing policy. Such a policy will ultimately be required if a reasonable and durable balance is to be achieved between the economic interests of the pig producer and the environmental interests of those using the vicinity to live, work and play.

On the basis of the issues explored in the full text, a number of general conclusions can be made to highlight the essence of the report:

1) A significant number of pig production units will require a licence, based on current National and European legislation

2) An assessment framework based on quantitative emissions is the most likely to achieve a transparent licensing practice that achieves a balance between the interests of the pig producer and those who use the surroundings as their living environment.

3) The proposed assessment framework identifies one environmental target for all situations. To allow for a degree of flexibility two limit values have been set, for new production unit applications and for existing facilities. The ‘space’ between the target and the limit values can be used in the licensing process to tailor the conditions to the specific requirements and opportunities that exist for that licence application.

4) The proposed framework for target and limit values is, in general terms, compatible with the setback distances required or advised in other countries, such as Germany, Netherlands, New Zealand.

5) The prevailing wind direction in Ireland causes a distribution of odours that is not entirely symmetrical. The actual meteorology of the location of the pig unit in question and the actual position of the receptor relative to the source, are therefore a factor in determining the setback distance required in a particular direction. These particular circumstances increase the need for specific modelling, in cases where the outcome is not clear-cut.

6) The geometric mean emission rate of 13.2 ou_E/s per finisher measured for winter conditions in Ireland for this study is about one third lower than the annual mean value of 22.6 ou_E/s per finisher found in a larger study in the Netherlands.

7) Given the relatively small number of samples, collected in the Irish study, and the statistical variance as derived from the larger Dutch study, the difference in the mean outcome is too small to be statistically significant.

8) It is therefore justified to use the emission factors derived in the Netherlands for emission estimates in Ireland, until emission factors specifically measured in Irish conditions are available for a larger sample of study sites.

9) The options for reducing odour emissions from pig production do exist. Reductions to 50% relative to the most common fully slatted production unit are quite feasible. However, the financial viability of many retrofit methods is an issue of concern, given the low economic returns on pig production.

10) The economics of installing the technology to abate odour emissions must be assessed before this technology can be imposed on existing pig unit operations.

11) The most viable low-emission options involve modification of pig houses, or replacement by new low emission design housing. Such structural abatement can only be reasonably achieved in the normal economic cycle of asset replacement, in most cases

12) Retro fitting of abatement systems, using air treatment systems such as bioscrubbers, chemical scrubbers or biofilters, can achieve significant

emission reductions of between 70% and over 95%. The main impediment is the additional cost incurred, which can increase the cost of a pig produced by roughly 10-20%. Market conditions in recent years, generally speaking, do not allow such an increased cost.

13) Good operational practice, including suitable landscaping, tree screens and pro-active community relations, remain a main factor in reducing annoyance and avoiding annoyance developing into nuisance.

14) A suitable production site for a given production capacity will become a major asset for any pig producer, which may become a main factor in determining the sustainability of the activity. Producers are well advised to use the planning process to their advantage and be pro-active in counteracting any encroachment into the existing setback zone by any developments that may be termed an ‘odour sensitive receptor’.

15) By making transparent the assessment of the impact of pig production on the vicinity, the proposed framework can contribute in practice to the protection of the interests of both pig producers and the general public.

Annex A. Odour regulations for intensive livestock in other countries

A.1 Germany

A.1.1 General regulatory framework and relevant guideline documents

The law concerning air quality issues in Germany is the Bundes Immissionsschutzgesetz (known as 'BimSchG'), or the Federal Immission Control act of 1990, which is available in English from the Ministry for Environment, Nature Conservation and Nuclear Safety.

All odours from any commercial installation are considered an annoyance, according to §3 of 'BimSchG'. For licensing and enforcement, however, the issue is to determine whether the annoyance constitutes a 'significant disturbance', on the basis of the 'relevance of the annoyance'. However, the 'BimSchG' does not provide for criteria to determine when an *annoyance* becomes a *significant disturbance* (nuisance).

The second relevant official regulatory document, aimed at providing technical guidance for specific industries on how to achieve the general principles concerning air quality in the 'BimSchG' also fails to provide operational annoyance criteria. *The Technische Anleitung zur Reinhaltung der Luft*, or TA-Luft, details the technical measures, expected to be applied in different sectors of industry and agriculture, including methods for assessment. The *TA-Luft* is available in English:

- *Technical Instruction on Air Quality control* (Erste Allgemeine *Verwaltungsvorschrift zum Bundesimmissionsschutzgesetz)*, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Bonn, 1986 (GBBl. P.95)

The *TA-Luft* defines a maximum 'odour frequency', as an ambient air quality characteristic, but does not specify a method to assess this parameter. In 1994 the Department of the Environment of Nordrheinland Westfalen introduced a method for this purpose, aimed at assessing ambient air quality for odours in the vicinity of an existing source. The document is available in English translation:

- *Determination and Evaluation of odour immissions - Odour exposure guideline* (Feststellung und Beurteilung von Geruchsimissionen - Geruchsimmissionsrichtlinie), Länderausschuß für Imissionsschutz, LAI-Schriftenreihe No. 5, Berlin 1994.

Table 19: Conversion table from pig life stages to German GV units, according to VDI3471

Conversion of pig numbers to GV, VD13471		
Animal stage		
Dry sow, boar	0.3	GV
Wet sow with progeny < 4 weeks	0.4	GV
Wet sow with progeny > 4 weeks	0.5	GV
Gilts	0.15	GV
Weaners ≤ 15 kg	0.01	GV
Weaners >15 kg and < 25 kg	0.02	GV
Fatteners (batch finishing) ≤ 45 kg	0.06	GV
Fatteners (batch finishing) > 45 kg	0.15	GV
Fatteners (continuous finishing) from 25 to 105 kg	0.12	GV

This method describes a method for long-term field panel observations, in which the fraction of 'odour hours' is determined by a team of assessors on pre-defined locations on a grid around the source in question. The method has been applied on pig units[9]. This method can be applied apply to determine licensing applications.

In most licensing cases, however, technical guidelines are applied, that provide detailed advice on the design and operation of pig units and other livestock operations:

- VDI3471:1986 Emission Control. Livestock management - Pigs
- VDI3471:1986 Emission Control. Livestock management - Hens

- VDI3473:1994 Part 1 (draft) Emission Control. Livestock farming - Cattle. Odourants.

In addition to technical guidance on the design and operation of pig units, the technical standard, VDI3471:1986 contains a graph providing setback distances, for pig units of different sizes. This graph is presented in Figure 10. In determining setback distances, operational methods and design of the pig unit are taken into account, using a system of assigning points. A correction on the standard setback distance can be applied on the basis of the total number of points.

If a pig unit complies with the VDI3471 standard, and is located so that the setback distances are respected, that is in most cases sufficient ground for the local authority to grant a licence. In those cases where the distance to residences is less than 100m, or in cases where the setback distances cannot be attained fully, expert advice is sought to determine the application, using detailed assessments, typically based on atmospheric dispersion modelling.

A.1.2 The distance graph in VDI3471

The capacity of a pig unit is expressed in ‘Grossvieheinheiten’ (GV), that are equivalent to 500 kg live weight. The number of GV in a pig unit is calculated using the conversion factors in Table 19.

For a typical Irish integrated unit, capacity for one integrated sow and progeny, including finishers, would be approximately equivalent to 1.3 GV.

Once the number of GV units has been determined, a point system is applied to take design and operational practice into account. The point system is summarised in Table 20.

For a 400-sow unit, which is close to the lower limit for licensing in Ireland, the setback distance would be between approximately 390 and 620m, depending on the number of points.

A.2 Netherlands

A.2.1 Guideline documents

The pig production sector in the Netherlands is

Table 20: Correction factors and their points value for use with the setback distance graph, VDI3471

Point system for setback distance graph, VDI3471	
Criteria	**Points**
Waste removal and storage	
Solid manure removal	
‘Tiefstall’	60
Mechanical manure removal to storage enclosed by walls on three sides	50
Mechanical manure removal to transport vehicle	40
Mechanical manure removal to open air manure heap	20
Liquid manure removal	
Slatted floors, >45%	10
Slatted floors, <45%	5
Mechanical removal	0
Slurry storage	
Storage tank fully enclosed	50
Storage with cover	30
Storage with full natural crust formed	30
Storage without cover	0
Underfloor storage in the pig house	30
Ventilation	
Summer ventilation rate, according to DIN18910	
Temperature difference ≤ 2 K	10
Temperature difference ≤ 3 K	5
Temperature difference > 3 K	0
Ventilation exit duct	
Vertical, height ≥ 1.5 m above roof apex	15
Vertical, height < 1.5 m above roof apex	5
Horizontal side vents	0
Vertical exit velocity at summer ventilation rate	
Velocity ≥ 12 m/s	25
10 ≤ velocity < 12 m/s	20
7 ≤ velocity < 10 m/s	10
Velocity < 7 m/s	0
Miscellaneous	
Special feeds, dry waste food	0
Kitchen wastes with weak odour	up to -10
Wastes with a strong odour	Up to -25
Location	Up to plus or minus 20
Slurry storage capacity	
≥ 6 months	10
≥ 5 months	5
≥ 4 months	0

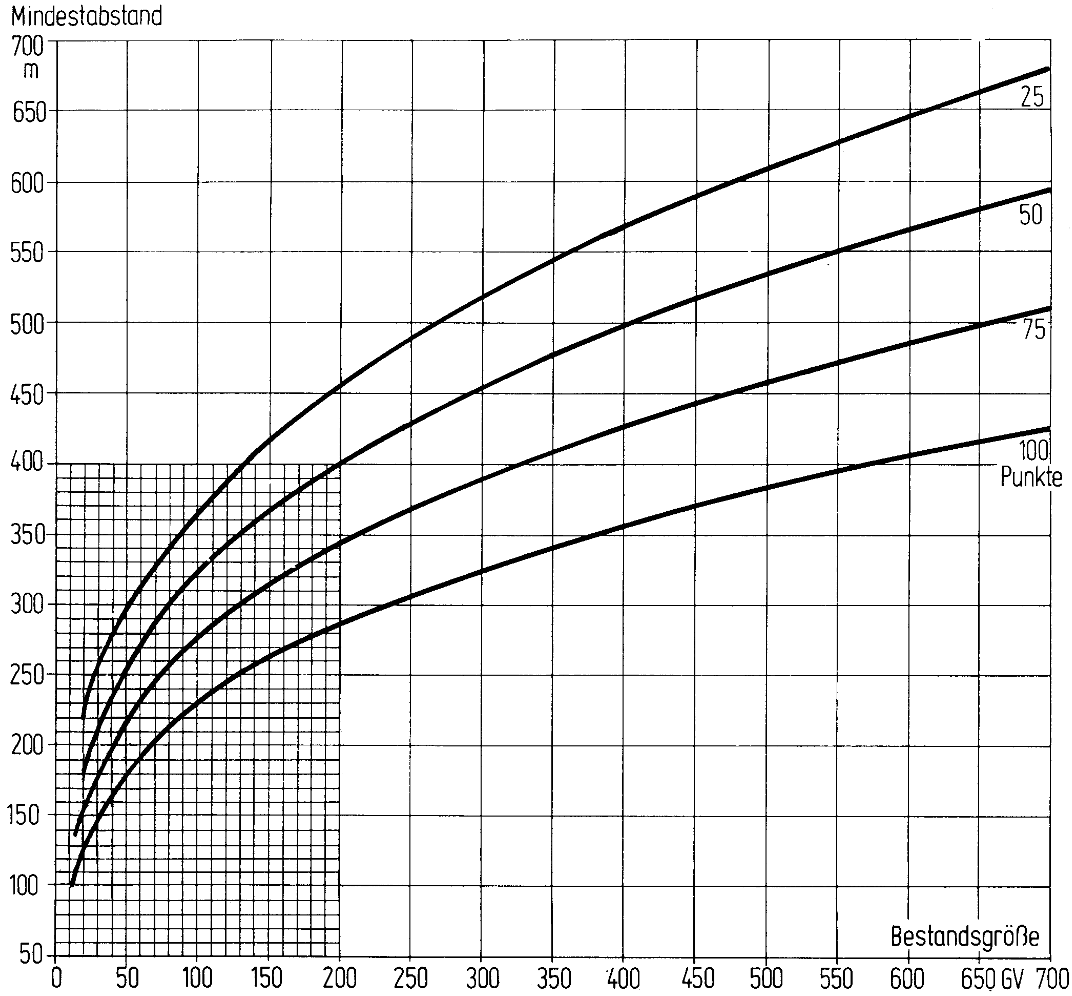


Bild 21. Abstandsregelung für Schweinehaltungen

Figure 10: Setback distances graph, for different numbers of 'Livestock Units' (GV), wit correction based on points for operational practice and design of the pig unit. Germany, VDI3471. One sow on an integrated unit in Ireland is approximately equivalent to 1.3 GV.

considerable in size, relative to both the size of the population and the surface area of the country. Annual production is approximately 30 million pigs, which amounts to 2 pigs per head of the population, There are 1.4 million places for sows and 7.4 million places for finishers in Dutch pig houses (1998). It is therefore not surprising that odour impact of pig production is a major environmental issue, given the high density and proximity of both residents and pigs. Very recently, in 2000, a considerable budget of more than 200 million Euro was made available by the Dutch government to buy out existing pig production units to reduce the capacity of the sector and its environmental impact.

The first guideline on how to take account of environmental odour aspects for licensing as a result of application of the existing the Nuisance Law was issued in 1971, and revised several times in later years: 1984 and 1996.

The successive guideline documents are:

- *Brochure Livestock Rearing and Nuisance Law* (1976)[25]
- *Guidance note on the application of the Nuisance Law on livestock production units* (1984)
- *Brochure on Livestock Production and Nuisance Law* (1985)
- *Assessment of accumulation by intensive livestock production*, Publication Series Air no. 46, Ministry of Public Planning and the Environment (1985)

- *Guideline Livestock Production and Odour Annoyance* (1996)

The guideline of 1996 is currently used. The main instrument for managing odour impact through licensing has been retained in all these successive guidelines, in the form of a graph relating the required setback distances to the number of animals in the pig production unit, see Figure 11. The size of a pig production facility is expressed in 'mestvarkeneenheden' or [mve], which translates to 'fattener units'. In many translated publications the less correct and confusing term 'pig units' has been used. One [mve] represents the emission of odours of one fattener, held in a traditional housing system (i.e. partly slatted) over one year.

There is a table for conversion of various animals and life stages to [mve]. In the 1996 guideline, the following numbers of animals are equivalent to 1 mve:

- 1 mve is equivalent to 11 weaners
- 1 mve is equivalent to 1.5 wet sows
- 1 mve is equivalent to 3.0 dry sows
- 1 mve is equivalent to 1.0 fatteners on a conventional, partly slatted system (and equivalent to 22.6 ou_E/s)
- 1 mve is equivalent to 1.4 fatteners held in a 'Green Label' low-emission housing system

The 'distance graph' provides four lines, differentiated for the category of the land use in the vicinity of the pig unit.

- **Category I** provides a higher degree of protection and is applied to non-agricultural, residential areas, hospitals, recreational accommodation etc.
- **Category II** is characterised by more disperse residential use in villages or hamlets, where the living environment has a rural character.
- **Category III** is for more or less isolated residences or clusters of residences in an otherwise rural environment.
- **Category IV** is the most lenient level of protection and is used for environments with farmhouses only.

The 'distance graph' has remained largely the same over the years. In 1996 the lines were extended for higher numbers of pigs. The main drive behind the 1996 revision was to find ways to allow further expansion of pig units that had reached the limits of their expansion possibilities. Although the 'distance graph' remained largely unchanged, the interpretation of the categories

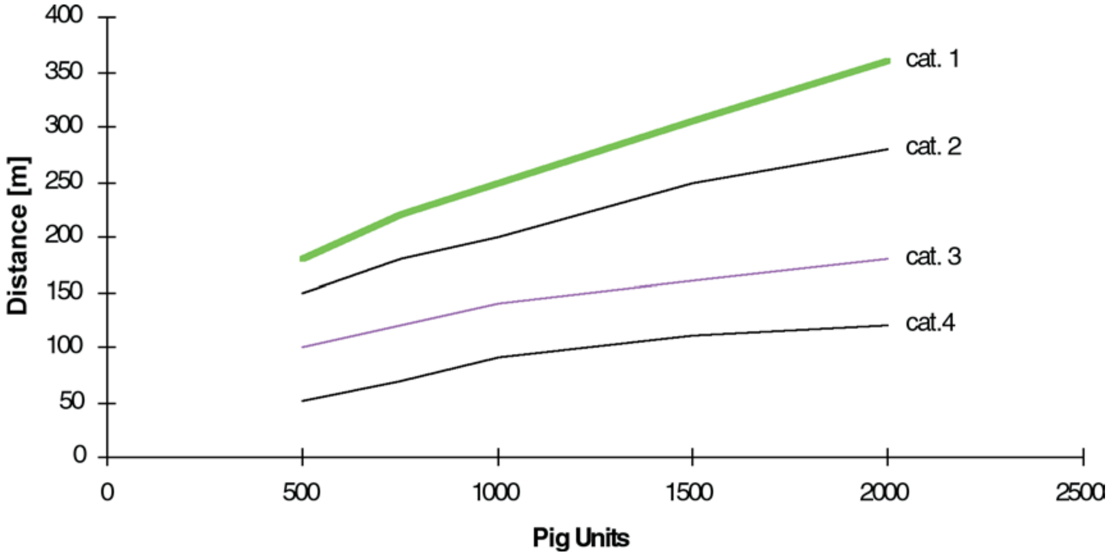


Figure 11 Setback distances for pig production units in the Netherlands, 500 to 2500 pig units (equivalent to fatteners), Brochure Hinderwet en Veehouderij, 1996

and the method of measuring distances between buildings and residences was adapted to allow some degree of further expansion, while maintaining the objective that no 'severe odour nuisance' should occur. Another modification concerned the conversion for various animals and life stages to [mve] units, which now included values for low emission housing, the certified 'Green Label' housing systems. Using the expanded table for these 'Green Label' systems allowed existing pig units to expand, providing that they used these low emission housing systems. .

In 1997 and 1998 a number of rulings of the Council of State, the highest appeal court for planning cases, have challenged parts of the revisions of 1996. Particularly the modifications in the application of the categories, that implied that a number of categories of residences were moved to a less protected category, was not accepted. The Council of Stated judged the motivation for the revisions insufficient. As a result, the Ministry of Public Planning and the Environment has started a number of research projects, to establish the scientific basis for the relation between exposure to pig odours and actual levels of annoyance. A second project involves the measurement of emission factors for different life stages of pigs. The results will be used as the starting point for a major policy review, named *Revision of policy instruments for rural odour policy*, with the Dutch acronym VIAS. The review is currently ongoing and is expected to lead to introduction of a fully revised guideline in autumn 2000 or early in 2001.

It is expected that the 'distance graph' will continue to be applied, but the use of four categories of land use may be simplified and adapted to reflect the results of the dose-effect studies. In addition, a revision of the conversion factors to [mve][for different life stages is expected to be revised, on the basis of recently measured values.

A.3 United Kingdom

The Environmental Protection Act of 1990 provides the legal framework for avoiding and controlling odour nuisance in the United Kingdom. The Environmental Health department of the Local Authority is responsible for its enforcement. Under Part III, Section 79 of the Act, the local authority has a duty to inspect their area and detect any statutory nuisance. Reasonably practicable steps are to be undertaken to investigate complaints by residents made to them.

Statutory Nuisances are defined in Section 79 of the Act. The relevant passages, relating to odour, are:

- …any dust, steam, smell or other effluvia arising on industrial, trade or business premises and being prejudicial to health or a nuisance;
- fumes or gases so as to be prejudicial to health or a nuisance;
- any animal kept in such a place or manner as to be prejudicial to health or a nuisance; and
- any other matter declared by any enactment to be a statutory nuisance.

Where a local authority Environmental Health Department is satisfied that a statutory nuisance exists, or is likely to occur or recur, it has a duty to serve an abatement notice under Part III, Section 80 of the Act requiring:

- the abatement of the nuisance or prohibiting or restricting its occurrence or recurrence; and
- the execution of such works and the taking of such other steps as may be necessary for these purposes.

A person served with an abatement notice may appeal to the Magistrates Court within 21 days of being served with the notice. In the event the person does not comply with the Abatement Notice fines up to GBP 20,000 may be imposed. In such cases, it is a defence to show that you have used the *best practicable means (BPM*) to prevent or counteract the nuisance. BPM is defined to have regard among other things to local conditions and circumstances, to the current state of technical knowledge and to the financial implications.

The law on statutory nuisance is far from straightforward. A key problem is that no criteria are provided to decide when occurrence of an odour constitutes a nuisance, and when it is acceptable. The system relies heavily on the individual judgement of the Environmental Health Inspector. In practice a wide variety of licence conditions occur.

Planning consents have to be granted on the basis of the Town and Country Planning (General Permitted Development) Order of 1995 (GPDO). New livestock facilities, such as livestock buildings, slurry storage facilities, and extensions or alterations to such facilities, need planning permission when these will be within a distance of 400m from the boundary of any protected buildings (such as residential houses or schools).

Under the Town and Country Planning (Assessment of Environmental Effects) Regulations of 1988 an environmental assessment is to be carried out for certain types of major project which are likely to have significant effects on the environment. For livestock units this requirement is likely to apply to new pig units of more than 400 sows or 5000 fatteners and new poultry units of more than 100,000 broilers or 50,000 layers.

For planning procedures, the use of odour modelling with application of a criterion of 5 ou_E/m^3 as a 98-percentile of hourly values has been accepted as an acceptable approach to demonstrate that no statutory nuisance would arise, in a planning enquiry involving a wastewater treatment plant at *Newbiggin-by-the-Sea*, Northumberland, planning reference APP/F2930/A/92 206240, UK, 1993[16].

The main document providing guidance is:

- *The Air Code*, Code of Good Agricultural Practice for the protection of Air, revised 1998, Ministry of Agriculture, Fisheries and Food and the Welsh Office Agriculture Departments, October 1998.

The Code provides general guidance on the legal background, and on good practice for production. The main part of guidance on odours is given in Part B of the Code, which contains a wealth of sound general advice, but is remarkably limited on technical detail and quantitative assessment and management information. The Code does not contain any specific recommendation on setback distances, other than suggesting that any pig unit located at less than 400 metres from residences should take extra care in implementing the advice given in the Code.

A.4 United States

Swine CAFO odours: Guidance for Environmental Impact Assessment, US EPA, Region 6, Dallas, Texas, contract no. 68-D3-0142, 1997

A.4.1 Setback distances:

The American Society of Agricultural Engineers (ASEA,1994) indicates that a ‘desirable distance’ for siting livestock facilities in general is 1600 m from housing developments and 400-800 m from neighbouring domestic dwellings.

The EPA guidance indicates that the setback distance should be at least 3.6 km and preferably 7.2 km for ‘larger facilities’.

A.5 New Zealand

A Code of Practice for pig production and siting is available on the Internet, at www-aghort.massey.ac.nz/centres/mrc/extension/cop

The New Zealand Code of Practice (CoP) contains two types of setback distances:

- Fixed setback distances, that must be observed in all cases, regardless of the size of the production unit

- Adjustable setback distances that depend on the size of operation and a set of correction factors for operational characteristics.

The adjustable setback distances must be applied to pig production units with 2000 pigs or more.

For any piggery having more than 5000 pigs, the potential to create adverse effects will have to be determined on an individual case basis. The size of the buffer zone for such a piggery will reflect this.

One pig is counted for the P-factor when it is older than 70 days. Breeding units with weaners only are counted using a conversion of 1 breeding sow = 5 pigs.

The fixed setback distances are listed below:

Table 21: Fixed setback distances for intensive pig production units, New Zealand.

Feature	Separation distance (meters)
Residential building on same site	50
Milking shed and yard	45
Slaughterhouse	50
Reservoir for domestic water supply	800
Well for domestic supply	30
Water course	20
Public highway	50
Property boundary (with adjoining paddocks)	20

The flexible setback distances are differentiated, depending on the land use of the area surrounding the pig unit. Three classes of land use are distinguished:

- Zone 1A - Piggery reference point to a residential zone in an urban area
- Zone 1B - Piggery reference point to a place of public assembly
- Zone 2 - Piggery reference point to a rural dwelling not on the same property

Depending on the zone the adjustable setback distance is determined on the basis of a table, relating the P factor to adjustable setback distance, see Table 22.

Table 22: P values and zone distances - standard piggery, New Zealand

P value (No. of pigs)	Zone 1A meters	Zone 1B meters	Zone 2 meters
Up to 2000	2000	1500	500
2500	2500	1875	625
3000	3000	2250	750
3500	3500	2675	875
4000	4000	3000	1000
4500	4500	3375	1125
5000	5000	3750	1250

There is a system to take into account good operational practice. Based on a number of operational characteristics, see Table 23, a *piggery reduction factor* can be calculated, the percentage by which the standard setback distance required can be reduced, up to 40% maximum:

Piggery reduction factor = 100 (1-[AxBxCxDxExFxG])

Specific setback distance calculations are included for situations where local topography or meteorology may have a significant influence in the odour exposure.

Table 23: Piggery reduction factors, New Zeland		
Designator	**Detail**	**Adjustment factor**
A	Emmissions to air from buildings	
	Weather by natural airflow or fan driven[1]	
	(1) Bio filtration of exhaust air	0.80
	(2) Ridge-ventilators plus trees (more than10 m high) surrounding the piggery compound	0.90
	(3) Ridge-ventilators only	0.95
	(4) Ridge & side-ventilators	0.90
	(5) Side ventilators only	1.00
B	Effluent collection system within all pig buildings	
	Faeces, urine and other biological material removed from the confines of the building	
	(1) Less than 12 hours old	0.75
	(2) As compost formed in sawdust bed penning system	0.75
	(3) While essentially aerobic but not greater than 30 hours old	0.90
	(4) Greater than 30 hours, but less than 4 days old	1.00
	(5) Greater than 4 days old	1.20
C	Effluent collection system outside all pig buildings (but within the piggery compound)	
	(1) Closed pipes (pig buildings to aerobic holding thank/pump)	0.95
	(2) Open channels (pig buildings to aerobic holding tank/pump)	1.00
D	Effluent treatment system(within the piggery compound)	
	(1) Anaerobic ponds(s) (inc. all inlet pipes/channels)	1.00
	(2) Facultative ponds(s) (inc. all inlet pipes/channels)	0.95
	(3) Aerobic pond(s)	0.60
	(4) Aerated pond(s) (aerobic surface layer over entire pond)	0.75
	(5) Composting using aeration or regular turning	0.80
E	**Noise**	
	(1) Maintaining noise recommendations **(see part 4)**	0.95
F	**Power supplies for ventilation, water supply, effluent handling and pumping**	
	(1) Reliable power supply (loss of supply for not more than an aggregate of 2 hours month)	0.95
	(2) Standby power supply for each 25% reduction in full load standby capacity	0.80 plus 0.05 per 25%

Table 23: Piggery reduction factors, New Zeland (continued)		
Designator	**Detail**	**Adjustment factor**
G	**Management**	
	Stock under surveillance:	
	24 hours/day	0.90
	12-23 hours/day	0.95
	6-11 hours/day	1.00
	1-5 hours/day	1.10
	less than 1 hour/day	1.20

Stock under surveillance shall mean that a person, qualified or competent to have charge of stock and deal with routine or emergency conditions is monitoring the fuctions of that piggery.

1 For ventilation requirements see:
British Standards Institution. (1990). BS 5502: 1990 Building & Structures for Agriculture. Part 42: Code of practice for design and construction of pig buildings. London. BSI

The Code of Practice - Pig Farming calls for a high standard at all piggeries, which is achieved by good management control of odour generating procedures. A piggery scoring a negative adjustment factor (i.e. an increase) in variable buffer zone distance would not meet the requirements of this Code of Practice.

Annex B. Methods for odour assessment and units of measurement

This annex describes the concepts used for characterising odours, the methods used for assessing odours and the units of measurement used.

B.1 Detectability

Detectability (or odour threshold) refers to the minimum concentration of odourant stimulus necessary for detection in some specified percentage of the test population. The odour threshold is determined by diluting the odour to the point where 50% of the test population or panel cannot detect the odour any more. The original odour concentration of an odour sample can be characterised by the number of dilutions to reach this detection threshold. At the detection threshold the odour concentration is 1 odour unit per metre cubed (ou_E/m^3). Threshold values are not fixed physiological facts or physical constants but statistically represent the best estimate value from a group of individual responses. Odour concentration is the most common attribute used to characterise odours. It provides the most common measure to characterise the magnitude of stimulus for determining the other attributes of an odour (the horizontal axis).

A European CEN standard method for measuring odour concentration is available[11], as described in the following sections. The European odour unit (ou_E) is pegged to a well-defined reference material, through the exclusive use of trained assessors selected for their specific sensitivity to the reference odour of n-butanol. In this manner the ouE has been made traceable:

$1\ ou_E/m^3 \int 40$ ppb/v n-butanol.

B.1.1 Measurement of odour concentration using olfactometry

Odour measurement is aimed at characterising environmental odours, relevant to human beings. As no methods exist at present that simulates and predict the responses of our sense of smell satisfactorily, the human nose is the most suitable ‘sensor’. Objective methods have been developed to establish odour concentration, using human assessors. A draft European CEN standard applies to odour concentration measurement:

CEN EN 13725:1999, *Air quality - Determination of odour concentration by dynamic olfactometry,* CEN/TC264/WG2 ‘Odours’, 1999

The odour concentration of a gaseous sample of odourants is determined by presenting a panel of selected and screened human subjects (Figure 12) with that sample, in varying dilutions with neutral gas, in order to determine the dilution factor at the 50% detection threshold (D_{50}). The odour concentration of the examined sample is then expressed as multiples of one European Odour Unit per cubic metre [ou_E/m^3] at standard conditions.

Figure 12: Dynamic olfactometry with human assessors, to measure odour concentration according to EN13725, photo courtesy of Odournet UK Ltd.

B.1.2 The unit of measurement

The odour unit is a difficult unit to define, because it relates a physiological effect to the stimulus that caused it. The stimulus, in this case, can be a multitude of substances. The way in which the response of our sense of smell is reduced to a single value of a parameter amounts to a gross simplification of the rich spectrum of sensory information that is actually perceived by the brain. Such a simplification may be useful, however, in describing potential effects. The reduction of a very complex set of physiological processes to a simple parameter is methodologically very similar to expressing the effects of toxic substances on an organism as the LD_{50}, indicating the dose that causes a lethal effect in 50% of a well-defined test population. The complex physiological response is regarded as the unifying reaction that can be caused by a wide range of substances, at an equally wide range of dosages. In general terms, this approach can be used to describe the potential of a certain amount of a substance to cause a physiological effect, by expressing the dose as a multiple of the dose that would cause an effect in 50% of a population. The definition and use of the unit are highly analogous to that of the odour unit. In odour research, the D50 could be described as the 50% of a population that can detect a sensory stimulus. In the past odour researchers have not used populations of standard test subjects, and have only related the physiological response to the number of dilutions of the dose of a sample to be measured. That practice implies a fundamental inability to compare the dosage of the samples through other means than the population itself. This can only be justified if the researcher is convinced that the samples of the population are sufficiently large to compensate for biological variability within this population. This assumption, however, cannot be fulfilled in the practice of odour measurement. The small sample from the population (4-8 subjects, more or less randomly chosen) is far too limited a sample to be representative, knowing the variability of sensitivity within the population. This practice does not comply with statistical requirements as used in toxicological experimental design, as the sample size from the population required to be representative (hundreds) is far larger than the regular number of panel members used in olfactometry for environmental applications.

The solution is to standardise the test subjects used to assess the sensory response. Reproducible results can be obtained by selecting panel members with a known sensitivity to an accepted reference material (now n-butanol CAS-nr [71-36-3]). The assumption made is that the sensitivity for the reference odourant will be a predictor for sensitivity to other substances. The dose of other substances and mixtures is then expressed in multiples of the dose that would elicit a physiological reaction equivalent to that of the reference. In practical terms: The European odour unit [ou_E] is that amount of odourant(s) that, when evaporated into 1 cubic metre of neutral gas at standard conditions, elicits a physiological response from a panel (detection threshold) equivalent to that elicited by one European Reference Odour Mass (EROM), evaporated in 1 cubic metre of neutral gas at standard conditions

One EROM, evaporated into 1 cubic metre of neutral gas at standard conditions, is equivalent to the D_{50} physiological response (detection threshold), assessed by an odour panel in conformity with this standard, and has, by definition, a concentration of 1 ou_E/m^3. There is one relationship between the ou_E for the reference odourant and that for any mixture of odourants. This relationship is defined only at the D_{50} physiological response level (detection threshold), where:

1 EROM (for n-butanol, CAS 71-36-3) ∫ 1 ou_E
for the mixture of odourants.

This linkage is the basis of traceability of odour units for any mixture of odourants to that of the reference odourant. It effectively expresses odour concentrations in terms of 'n-butanol mass equivalents'.

The odour concentration is expressed as a multiple of one ou_E in a cubic metre of neutral gas. The odour concentration can only be assessed at a presented concentration of 1 ou_E/m^3. The odour concentration, in ou_E/m^3, can be used in the same manner as mass concentrations (kg/m^3).

Note: *When using odour concentrations one should be aware that the relationship between the odour intensity and the odour concentrations is not linear, and may be a different relationship for different (mixtures of) odourants.*

B.1.3 Odour concentration measurement using quantitative olfactometry

The odour concentration of a gaseous sample of odourants is determined by presenting a panel of selected and screened human subjects with that sample, varying the concentration by diluting with neutral gas, in order to determine the dilution factor at the 50% detection threshold ($Z_{50} \equiv \bar{Z}_{ITE,pan}$).

At that dilution factor, the odour concentration is 1 ou_E/m^3 by definition. The odour concentration of the examined sample is then expressed as a multiple (equal to the dilution factor at Z_{50}) of 1 European odour unit per

Table 24: Confidence interval for replicated measurements using dynamic olfactometry								
n	$2{,}0 \cdot \frac{s_r}{\sqrt{n}}$	$10^{2{,}0 \cdot \frac{s_r}{\sqrt{n}}}$	lower limit log(ou_E/m^3)	*m*	upper limit log(ou_E/m^3)	Lower limit ou_E/m^3	*m*	upper limit ou_E/m^3
1	0.3443	2.2093	2.6557≤	3.0	≤3.3443	453≤	1000	≤2209
2	0.2434	1.7516	2.7566≤	3.0	≤3.2434	571≤	1000	≤1752
3	0.1988	1.5804	2.8012≤	3.0	≤3.1988	633≤	1000	≤1580
4	0.1721	1.4864	2.8279≤	3.0	≤3.1721	673≤	1000	≤1486
5	0.1540	1.4255	2.8460≤	3.0	≤3.1540	702≤	1000	≤1425
6	0.1405	1.3821	2.8595≤	3.0	≤3.1405	724≤	1000	≤1382
7	0.1301	1.3493	2.8699≤	3.0	≤3.1301	741≤	1000	≤1349
8	0.1217	1.3235	2.8783≤	3.0	≤3.1217	756≤	1000	≤1323
9	0.1148	1.3024	2.8852≤	3.0	≤3.1148	768≤	1000	≤1302
10	0.1089	1.2849	2.8911≤	3.0	≤3.1089	778≤	1000	≤1285

cubic metre (ou_E/m^3) at standard conditions for olfactometry (Room temperature (293 K), normal atmospheric pressure (101,3 kPa) on a wet basis).

The measurement must be carried out with a selected panel. The method should comply fully with the CEN standard EN13725.

The performance of odour concentration measurements has been defined in the performance criteria of the standard. These imply that for one single measurement result, the 95% confidence interval will be:

The geometric repeatability of the sensory calibration with n-butanol is r' ≤ 3, complying with the EN13725. The confidence limits for a value x for two measurements (k=2) is:

$$x \cdot 2.09^{-1} \leq x \leq x \cdot 2.09$$

In other words, if the real concentration is 1000, the result of analysis will in 95% of cases lie in the interval between 478 and 2090 ou_E/m^3. Analysing more than one replicate of a sample can reduce the uncertainty. Table 24 shows the 95% confidence interval for replicated measurements, for the repeatability that is required in the EN13725 standard.

For the assessment of the efficiency of an odour abatement unit, the repeatability is an important consideration. Again assuming the repeatability required in the CEN standard EN13725, Table 25 gives confidence intervals for the filter efficiency in relation to the number of samples taken both before and after the abatement unit *n*, when the actual efficiency is 90%.

Table 25: Confidence interval for determining the abatement efficiencyusing dynamic olfactometry, for different numbers of replicates				
n	n_{od}	Lower limit confidence interval	$1\text{-}10^{m_D} = n_{od}$	Upper limit confidence interval
1	90	69.3%	≤90.0%	≤96.7%
2	90	77.9%	≤90.0%	≤95.5%
3	90	80.9%	≤90.0%	≤94.8%
4	90	82.5%	≤90.0%	≤94.3%
5	90	83.5%	≤90.0%	≤93.9%
6	90	84.2%	≤90.0%	≤93.7%
7	90	84.7%	≤90.0%	≤93.5%
8	90	85.1%	≤90.0%	≤93.3%
9	90	85.5%	≤90.0%	≤93.1%
10	90	85.7%	≤90.0%	≤93.0%

B.2 Intensity

Intensity is the second dimension of the sensory perception of odourants, which refers to the perceived strength or magnitude of the odour sensation. Intensity increases as a function of concentration. The relation between perceived intensity and the *logarithm* of odour concentration is linear.

Odour intensity refers only to the magnitude (strength) of the perception of an odour. Intensity has a second meaning, in that it can refer to the magnitude of the stimulus causing the perception.

The relationship between perceived intensity I and the stimulus may be described as a theoretically derived logarithmic function according to Fechner:

$$S = k_w \cdot \log {}^{I}/_{I_\circ} \qquad (A.1)$$

where

S	perceived intensity of sensation (theoretically determined)
I	physical intensity (odour concentration)
$I_\circ$	threshold concentration
k_w	Weber-Fechner coefficient

or as a power function according to Stevens:

$$S = k \cdot I^{n} \qquad (A.2)$$

where

S	perceived intensity of sensation (empirically determined)
I	physical intensity (odour concentration)
n	Stevens' exponent
k	a constant

Which one of these two descriptions applies depends on the method used. To date no theory has been able to derive the psychophysical relationship from knowledge about the absolute odour threshold of various substances.

The method for measuring intensity is derived from the following standard documents:

- VDI 3882:1997, part 1, *Determination of Odour Intensity*, Düsseldorf, Germany.

The principle of measurement is the presentation of the odour to human assessors in an odour panel, at varying degrees of dilution, hence varying perceived intensity.

The members of a panel of assessors are asked to indicate perceived intensity at each presentation as a value for the perceived intensity I on the seven-point intensity scale:

1	no odour
2	very faint odour
3	faint odour
4	distinct odour
5	strong odour
6	very strong odour
7	overwhelming odour

The values for I are then plotted against the logarithm of the odour concentration or the dilution factor. The regression line characterises the relation between perceived intensity and odour concentration, see Figure 3. The point where the regression line intersects with the horizontal axis is equivalent to the detection threshold.

By comparing the slope of the regression line for different odours they can be characterised. Some odours cause a rapid increase in perceived intensity with increasing concentration (such as NH_3). Other odours cause only a slow rise of perceived intensity, such as commercial toilet air fresheners that are designed to be perceived at a similar intensity, regardless of dilution.

B.3 Odour quality (descriptive)

Odour quality is the third dimension of odour. It is expressed in descriptors, i.e. words that describe what the substance smells like. This is a qualitative attribute that is expressed in words, such as *fruity*.

B.4 Hedonic tone

Hedonic Tone is the fourth dimension of odour. This is a category judgement of the relative like (pleasantness) or dislike (unpleasantness) of the odour. The method for measuring intensity is derived from the following standard documents:

VDI 3882:1997, part 2; *Determination of Hedonic Tone*, Düsseldorf, Germany

The principle of measurement is presentation of the odour to human assessors in an odour panel, at varying degrees of dilution; hence varying perceived intensity and hedonic tone.

The members of a panel of assessors are asked to indicate perceived hedonic tone at each presentation as a value from the nine-point hedonic tone scale:

+4	very pleasant
+3	pleasant
+2	moderately pleasant
+1	mildly pleasant
0	neutral odour / no odour
-1	mildly unpleasant
-2	moderately unpleasant
-3	unpleasant
-4	offensive

For each concentration level, the mean of the values for *H* of all panel members is calculated, and plotted against the odour concentration in ou_E/m^3. A fictitious example of the plotted result is presented in Figure 13 on this page. Using a suitable curve-fitting procedure a line can be fitted through the points obtained in the experiment. Using this interpolation, characteristic values can be derived from the plot, such as the odour concentration at *H = -2*.

B.5 Annoyance potential

Annoyance potential is a proposed attribute to quantify the propensity of an odour to cause annoyance within a population when exposed to this odour intermittently, over a long period of time. Annoyance potential is likely to be a function of both odour quality and hedonic tone in addition to perceived intensity (and odour concentration). The exact nature of the interaction between the dimensions of odour, which may help to define the potential of that odour to cause annoyance, has yet to be clarified. Once a method is available it will help in the definition of differentiated air quality standards for specific odours.

B.6 Characterisation of odours using chemical analysis

The characterisation of odours on the basis of measurement of concentrations of chemicals is only possible in those situations where one chemical is dominant in terms of odour perception. This is only rarely the case.

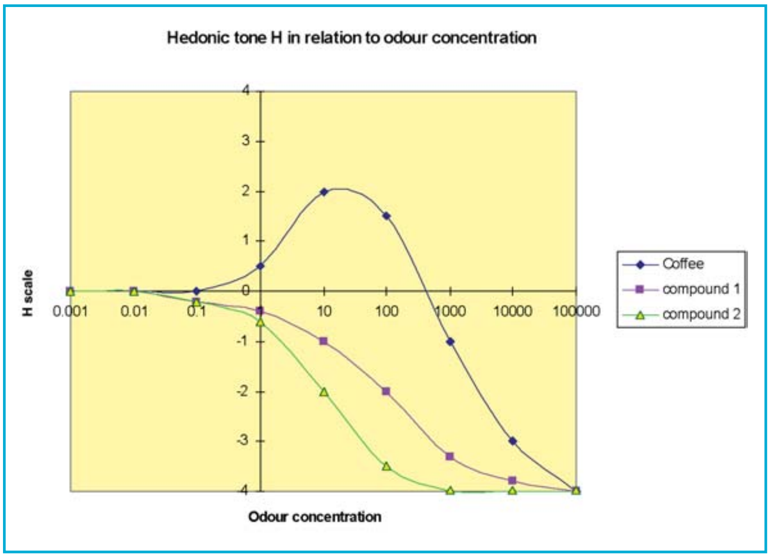


Figure 13: Hedonic tone as a function of odour concentration

Annex C. Glossary

accuracy: Closeness of agreement between test result and the accepted reference value.

(sensory) adaptation: Temporary modification of the sensitivity of a sense organ due to continued and/or repeated stimulation. **[ISO 5492:1992]**

amenity: The quality of being pleasing or agreeable in situation, prospect, disposition etc. [Websters Encyclopedic Unabridged Dictionary]

anosmia: Lack of sensitivity to olfactory stimuli. [ISO 5492:1992]

assessor: Somebody who participates in odour testing.

Best Available Technique (BAT) The most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where it is not practicable, generally to reduce emissions and the impact on the environment as a whole.

- "Techniques" include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned.
- "Available" techniques mean those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator.
- "Best" means most effective in achieving a high general level of protection of the environment as a whole. [IPPC directive 96/61, 1996, article 2, sub 11]

detection threshold, (for a reference material): The odourant concentration which has a probability of 0.5 of being detected under the conditions of the test.

detection threshold (for an environmental sample): The dilution factor at which the sample has a probability of 0.5 of being detected under the conditions of the test.

diffuse sources: Sources with defined dimensions (mostly surface sources) which do not have a defined waste air flow, such as waste dumps, lagoons, fields after manure spreading, non-aerated compost piles.

dilution factor: The dilution factor is the ratio between flow or volume after dilution and the flow or volume of the odorous gas. [AFNOR X 43-104E, see bibliography, Appendix J]

dynamic olfactometer: A dynamic olfactometer delivers a flow of mixtures of odorous and neutral gas with known dilution factors to a common outlet. [AFNOR X 43-101E, modified, see bibliography, Appendix J]

dynamic olfactometry: Olfactometry using a dynamic olfactometer

emission factor: The emission per unit product. (e.g. for wastewater treatment works expressed in this report the emission rate in ou_E/s per kg BOD, in screened sewage)

European odour unit, ou_E/m^3 : That amount of odourant(s) that, when evaporated into 1 cubic metre of neutral gas at standard conditions, elicits a physiological response from a panel (detection threshold) equivalent to that elicited by one European Reference Odour Mass (EROM), evaporated in one cubic metre of neutral gas at standard conditions

European Reference Odour Mass , EROM : The accepted reference value for the European odour unit, equal to a defined mass of a certified reference material. One EROM is equivalent to 123 µg n-butanol (CAS 71-36-3). Evaporated in 1 cubic metre of neutral gas this produces a concentration of 0.040 µmol/mol.

forced choice method: For this standard the following definition applies: An olfactometric method in which assessors are forced to make a choice out of two or more air flows, one of which is the diluted sample, even if no difference is observed.

fugitive sources: Elusive or difficult to identify sources releasing undefined quantities of odourants e.g. valve and flange leakage, passive ventilation apertures etc.

hedonic tone: attribute of an odour, indicating like or dislike

individual threshold estimate, ITE : The detection threshold applying to an individual estimated on the basis of one dilution series.

lower detection limit, LDL : Lowest value of the air quality characteristic which, with 95% probability, can be distinguished from a zero sample [ISO 6879].

neutral gas : Air or nitrogen that is treated in such a way that it is as odourless as possible and that does, according to panel members, not interfere with the odour under investigation.
Safety Warning: Nitrogen is only used to predilute the sample itself. For the olfactometer the neutral gas used to dilute the sample and present a reference shall be air.

objective method: Any method in which the effects of personal opinions are minimised. [ISO 5492]

odourant**—** A substance which stimulates a human olfactory system so that an odour is perceived.

odourant flow rate: The odourant flow rate is the quantity of odorous substances passing through a defined area at each time unit. It is the product of the odour concentration c_{od} and the outlet velocity v and the outlet area A or the product of the odour concentration c_{od} and the pertinent volume flow rate $\dot{V}$. Its unit is ou_E/h (or ou_E/min or ou_E/s, respectively.)
Note: The odourant (emission) flow rate is the quantity equivalent to the emission mass or volume flow rate, for example in dispersion models.

odorous gas: Gas that contains odourants.

odour: Organoleptic attribute perceptible by the olfactory organ on sniffing certain volatile substances. [ISO 5492]

odour abatement efficiency: The reduction of the odour concentration or the odourant flow rate due to an abatement technique, expressed as a fraction (or percentage) of the odour concentration in the odourant flow rate of the untreated gas stream.

odour concentration: The number of European odour units in a cubic metre of gas at standard conditions.
Note: The odour concentration is not a linear measure for the intensity of an odour. Steven's Law describes the a-linear relation between odour stimulus and its perceived intensity. When using odour concentrations in dispersion modelling, the issue is complicated by the effects of the averaging time of the dispersion model, further complicating the use of the odour concentration as a direct measure for dose. To define a 'no nuisance level', the entire method of dosage evaluation, including the dispersion model, will yield a 'dose'. The relation between this 'dose' and its effect (odour annoyance) should be validated in practical situations to be a useful predictive tool for occurrence of odour nuisance.

odour detection: To become aware of the sensation resulting from adequate stimulation of the olfactory system.

odour panel: See panel.

odour sensitive receptor: The closest fixed building or installation where odour annoyance may occur, such as residential homes, school, hospital, overnight facility for holidays etc.

odour threshold: See panel threshold.

odour unit: See European Odour Unit

olfactometer: Apparatus in which a sample of odorous gas is diluted with neutral gas in a defined ratio and presented to assessors.

olfactometry: Measurement of the response of assessors to olfactory stimuli. [ISO 5492]

olfactory: Pertaining to the sense of smell. [ISO 5492]

olfactory receptor: Specific part of the olfactory system which responds to an odourant. [after ISO 5492]

olfactory stimulus: That which can excite an olfactory receptor. [ISO 5492, modified]
panel: A group of panel members.

panel member: An assessor who is qualified to judge samples of odorous gas, using dynamic olfactometry within the scope of this standard.

panel selection: Procedure to determine which assessors are qualified as panel members.

panel threshold: Detection threshold applying to a panel.

perception: Awareness of the effects of single or multiple sensory stimuli. [ISO 5492]

population (detection) threshold: Detection threshold applying to the general population, if this population is not specified.

proficiency testing: The system for objectively testing laboratory results by an external agency.

quality: The totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs. [ISO 6879]

quality assurance: All those planned and systematic actions necessary to provide adequate confidence that a product, process or service will satisfy given requirements for quality. [ISO 6879]

recognition threshold: The odour concentration which has a probability of 0.5 of being recognised under the conditions of the test (definition not applied in this standard).

repeatability: Precision under repeatability conditions. [ISO 5725-part 1]

repeatability conditions: Conditions where independent test results are obtained with the same method on identical test material in the same laboratory by the same operator using the same equipment within short intervals of time. [ISO 5725-part 1]

reproducibility: Precision under reproducibility conditions. [ISO 5725-part 1]

reproducibility conditions: Conditions where test results are obtained with the same method on identical test material in different laboratories with different operators using different equipment. [ISO 5725-part 1]

sensitive receptor: see **odour sensitive receptor**:

sensory fatigue: Form of adaptation in which a decrease in sensitivity occurs. [ISO 5492]

to smell: To detect or to attempt to detect an odourant.

specific emission rate: The emission rate per unit of area of liquid or solid

standard conditions for olfactometry: At room temperature (293 K), normal atmospheric pressure (101.3 kPa) on a wet basis [as in ISO 10780].
Note: This applies both to olfactometric measurements and volume flow rates of emissions.

static olfactometer: A static olfactometer dilutes by mixing two known volumes of gas, odorous and odourless, respectively. The rate of dilution is calculated from the volumes. [AFNOR X 43-101E, see bibliography, Appendix J]

step factor: The factor by which each dilution factor in a dilution series differs from adjacent dilutions.

subjective method: Any method in which the personal opinions are taken into consideration. [ISO 5492]

substance: Species of matter of definite chemical composition.

test result: The value of a characteristic obtained by completely carrying out a specific measurement, once.

volatile organic compound: organic substance that will readily evaporate from a liquid into gas phase.

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Annex E. Contour plots for screening assessment

Plots with standard contours are provided as a means to carry out a quick screening assessment. The contours are provided at scale: 1:50.000 for the limit value for new pig units and the target value, and at scale 1:10,560 for the limit value for existing pig units.

To calculate these contour lines, the COMPLEX atmospheric dispersion model was used to calculate overlay contours. This US-EPA model, which is based on the widely used MPTER and ISC models, has been adapted by OdourNet to accommodate numerous sources (up to 999 sources) and to provide percentile values that are used to evaluate odour impacts that by their nature have very much shorter time frames to cause effects in receptors than most other common forms of air pollution.

For a detailed description of this model the following references are available:

[32] EPA, *Guideline on air quality models (revised)*, July 1986, EPA, EPA-450/2-78-027R.

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For the standard overlay contours, the hourly meteorological data for a Claremorris meteorological station were used, for the years 1993 to 1995 (inclusive). The wind rose for the data-set used is presented graphically in Figure 14.

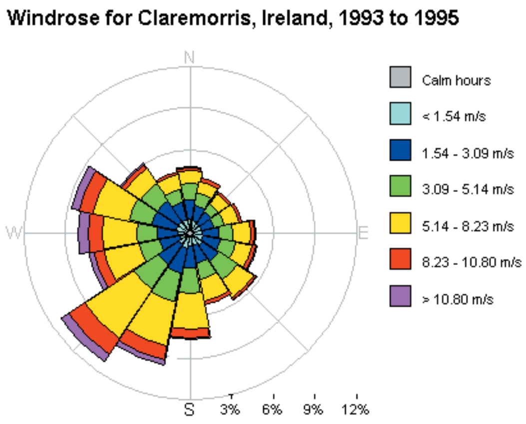

Figure 14: Wind rose for meteorological station Claremorris, hourly observations, period 1993 to 1995 (inclusive).

E.1 Standard contours overlay, scale 1:50,000, for the limit value for new pig production units,

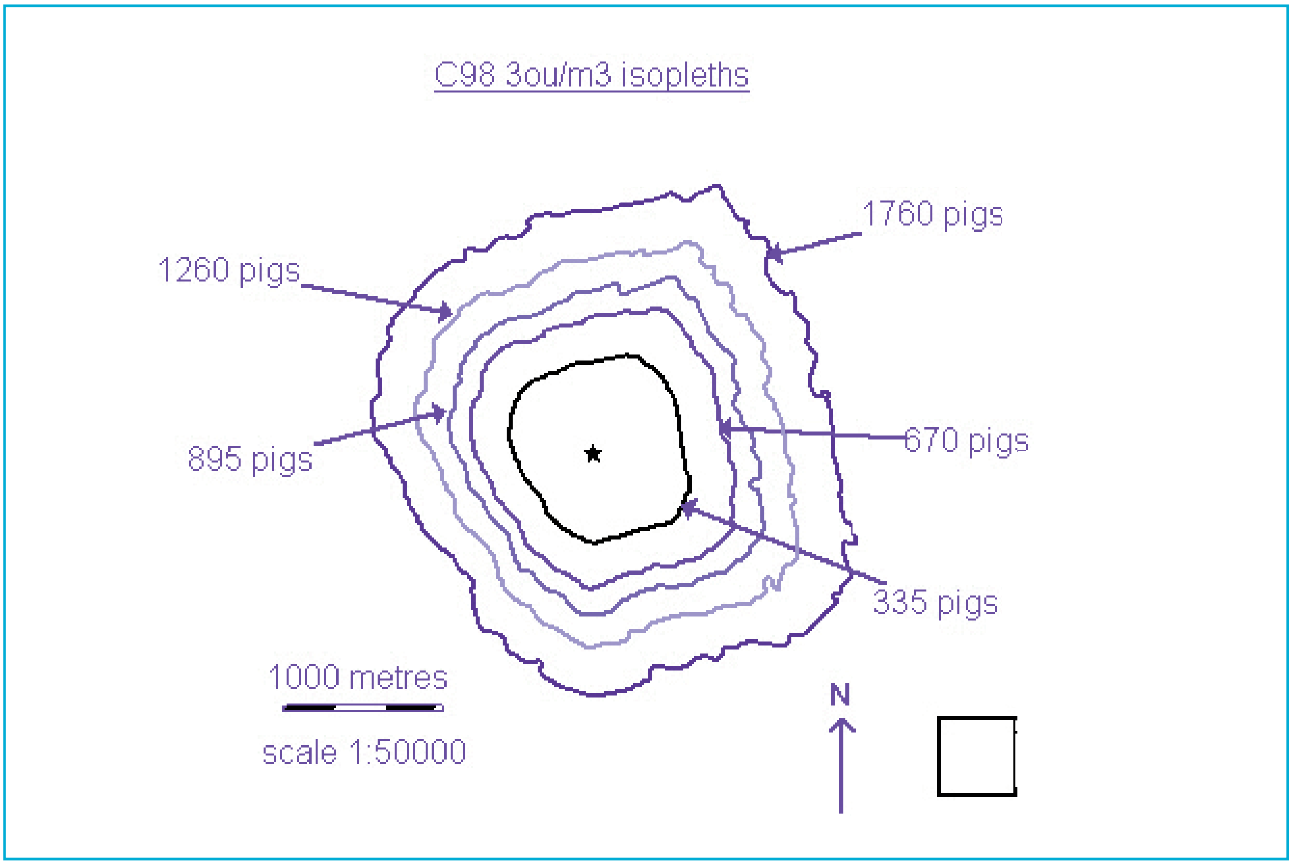

Figure 15: Standard contour overlay, representing typical contours for the limit value for new pig production units of C98, 1-hour = 3 ou_E/m^3 , for integrated sow units of different sizes, scale 1:50,000.

[note: Please ensure that reproduction has not distorted the image. This can be achieved by measuring the box at the bottom right of the image and ensuring that it is 1cm x 1cm]

E.2 Standard contours overlay, scale 1:50,000, for the target value for all pig production units

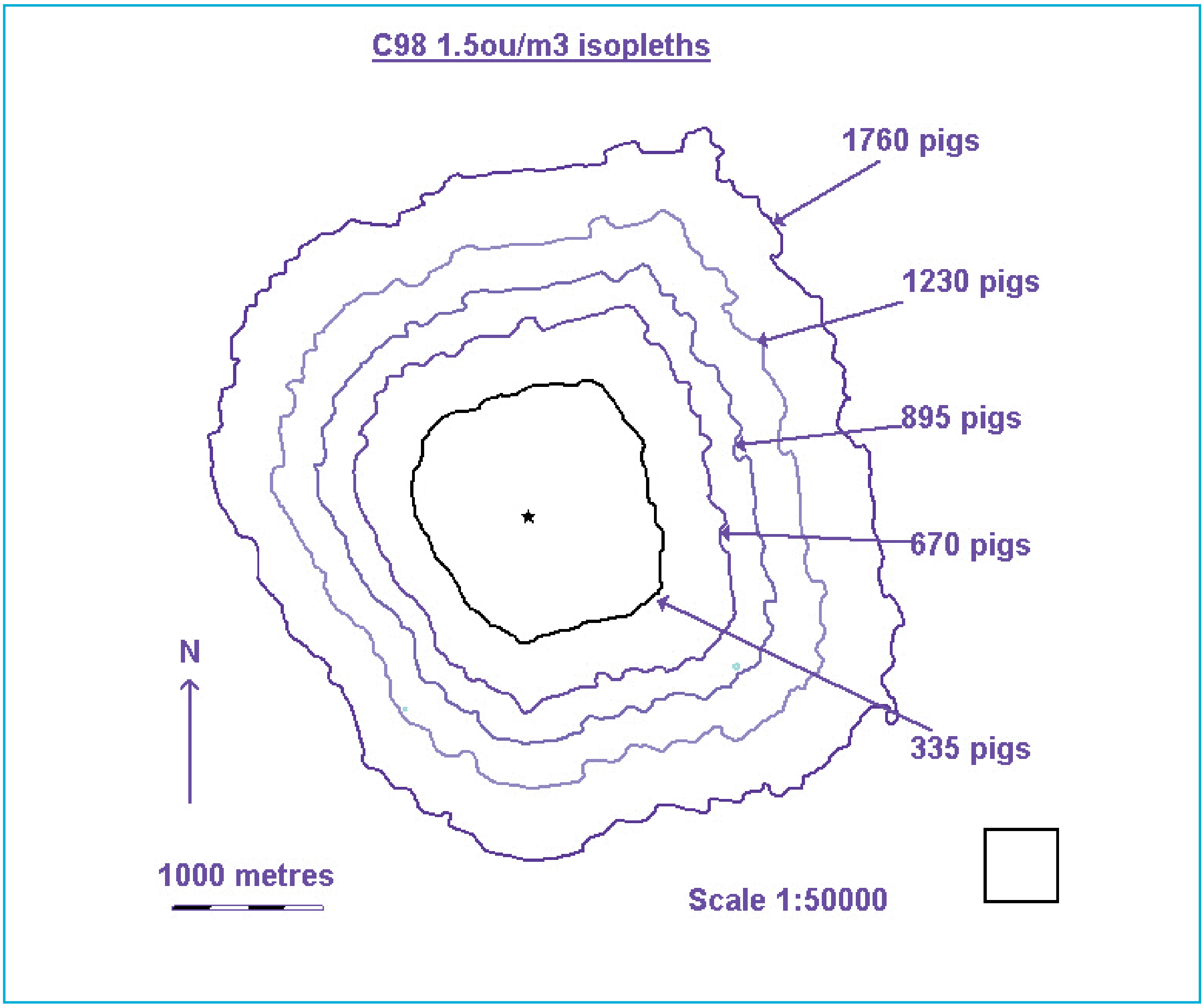

Figure 16: Standard contour overlay, representing typical contours for the target value for all pig production units of C98, 1-hour = 1.5 ou_E/m^3 , for integrated sow units of different sizes, scale 1:50,000.

[note: Please ensure that reproduction has not distorted the image. This can be achieved by measuring the box at the bottom right of the image and ensuring that it is 1cm x 1cm]

E.3 Standard contours overlay, scale 1:10,560, for the limit value for existing pig production units.

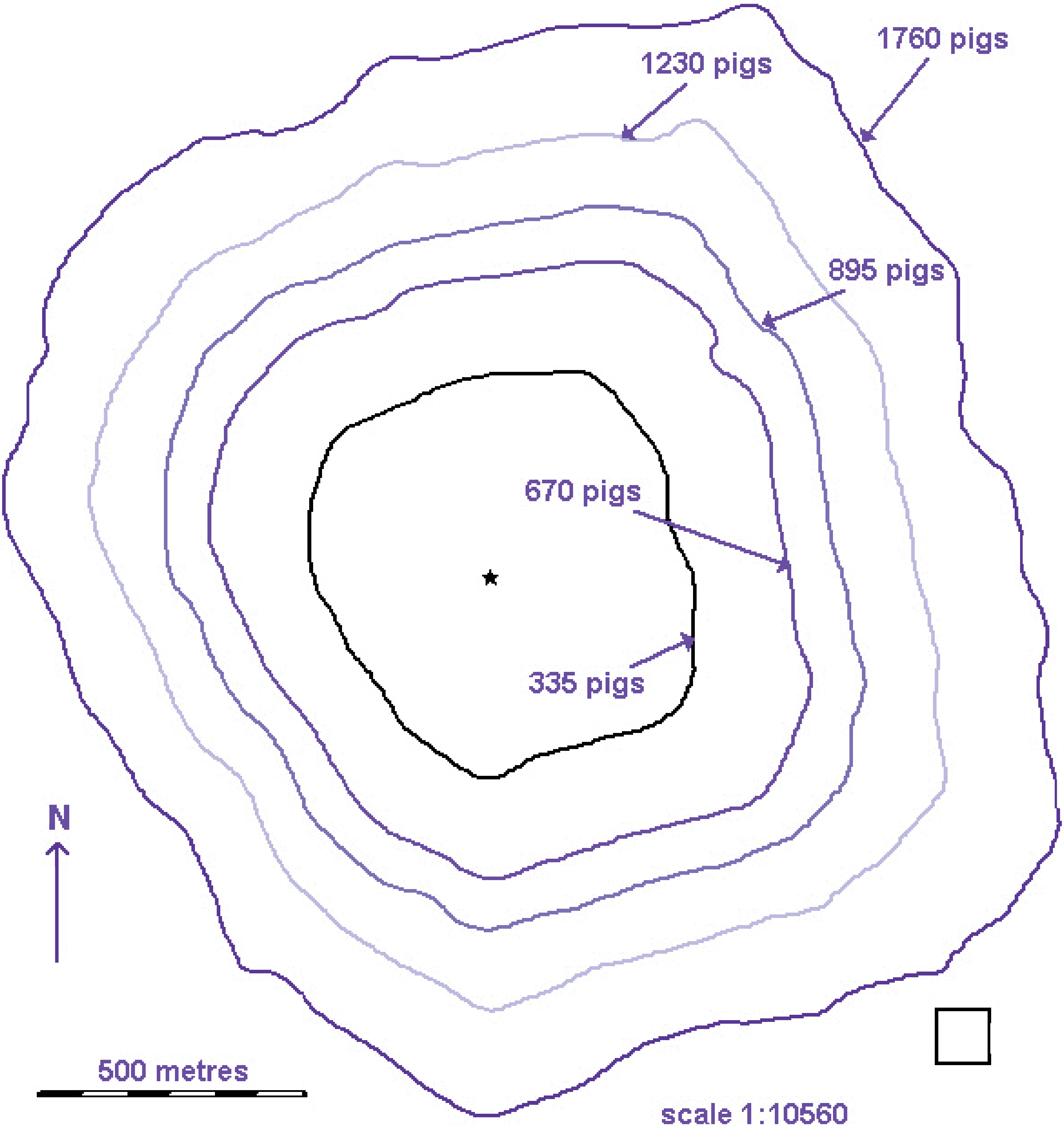

Figure 17 Standard contour overlay, representing typical contours for the limit value for existing pig production units of C98, 1-hour = 6 ou_E/m^3 , for integrated sow units of different sizes, scale 1:10,560.

[note: Please ensure that reproduction has not distorted the image. This can be achieved by measuring the box at the bottom right of the image and ensuring that it is 1cm x 1cm]

ODOUR IMPACTS AND ODOUR EMISSION CONTROL MEASURES FOR INTENSIVE AGRICULTURE

Part B *Case studies assessing the odour emissions and impact of two pig production units in the Irish Situation*

Project information

This report was commissioned by:
Environmental Protection Agency
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Contact: Dr. Vera Power / Dr. Tom Stafford

and was issued by:
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Copyright notice

Sources of information used

The following sources of information were among those used in preparing this report:

- Scale site plans provided by farm representatives
- Information collected during site survey by Odournet consultants
- The draft report of the Dutch IMAG data

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The authors wish to thank the owners and operators of farms A and B, the officers involved and all others who provided the information on which this report is based, for their cooperation.

Contents

Executive Summary

The Environmental Protection Agency has initiated a study into Odour Impacts and *Odour Emission Control Measures for Intensive Agriculture*, with the objective to assist the Agency in formulating its approach for processing the license applications with a view to achieving transparent and uniform decision-making.

In the course of this project two case studies were conducted to assess the odour impact of pig production units in the Irish context. At these locations odour emission measurements were conducted and dispersion modelling was used to assess the odour impact. Abatement options were considered to reduce the impact.

The objectives of these case studies was:

- To illustrate the approach as outlined the main Agency study *Odour Impacts and Odour Emission Control Measures for Intensive Agriculture*

- To obtain a limited set of emission measurements for Irish conditions, to assess whether these are significantly different from the distribution of results found in the much larger data set from the Netherlands[5, 10].

The case studies were not intended to provide a representative overview representative for most Irish pig units. The scope of the case studies and is too limited to do so. Similarly, the scale of the emission measurements was not sufficient to yield specific emission factors for Irish conditions.

The case studies prompted the following conclusions:

Conclusions on the results of finisher emission rate measurements in Ireland

The emission rate of 13.2 ou_E/s per finisher measured in Ireland for this study in winter conditions is about one third lower than the annual mean value of 22.6 ou_E/s per finisher found in a larger study in the Netherlands

Given the relatively small number of samples, collected in the Irish study, and the statistical variance as derived from the larger Dutch study, the difference in the mean outcome is too small to be statistically significant. Therefore, it is justified to use the emission factors derived in the Netherlands for emission estimates in Ireland, as long as emission factors specifically measured in Irish conditions are not available for a larger sample of study sites.

Odour impact study Farm A

Farm A is a large integrated unit, containing over 17000 animals. It is therefore no surprise that total emissions are high, and the odour footprint relatively large. However, given the locality of the farm - its distance from residential units and its rural context, there seems to be no urgency as no complaints have been registered. The only concerns resulting from the site visits were the uncovered slurry store and carcass skips. It is the opinion of Odournet UK that these sources may become a significant emitter of odours during the warmth of summer. However, having undertaken sampling during a cool spring day, there is no quantitative data to support this.

The modelling shows that in the current situation a limited number of (ten) dwellings may be affected by odour impacts in excess of the limit value. It is therefore necessary to seriously consider options to reduce emissions. In the short-term measures to reduce emissions from sludge storage should be considered. In the longer term, replacement of housing assets could reduce the number of dwellings exposed to odour impacts in excess of the limit value, conceivably to zero. The target value will be difficult to attain for farm A. The farm can be made sustainable at current stock levels, from the perspective of odour impact, provided that the community recognises and accepts the rural context in the vicinity.

Odour impact study Farm B

Farm B is a relatively small-scale operation. Under current circumstances, four properties fall within the odour footprint and therefore may be affected by odour impacts in excess of the limit value. This farm would require to consider the implementation of abatement options if current stock numbers are maintained.

In the long term, a reduction of odour emissions should be considered when normal renewal of pig housing assets becomes an issue. This could achieve attainment of the limit value for all dwellings in the vicinity, and possibly create room for some growth of stock when the agricultural context of the area is recognised and accepted as the status quo.

1. Scope of study

1.1 Scope

The Environmental Protection Agency has initiated a study into *Odour Impacts and Odour Emission Control Measures for Intensive Agriculture*, with the objective to assist the Agency in formulating its approach for processing the license applications with a view to achieving transparent and uniform decision-making.

In the course of this project two case studies were conducted to assess the odour impact of pig production units in the Irish context. At these locations odour emission measurements were conducted and dispersion modelling was used to assess the odour impact. Abatement options were considered to reduce the impact.

The objectives of these case studies was:

- To illustrate the approach as outlined the main Agency study *Odour Impacts and Odour Emission Control Measures for Intensive Agriculture* (Part A)
- To obtain a limited set of emission measurements for Irish conditions, to assess whether these are significantly different from the distribution of results found in the much larger data set from the Netherlands[5, 10].

The case studies were not intended to provide a representative overview representative for most Irish pig units.

Similarly, the scale of the emission measurements was not sufficient to yield specific emission factors for Irish conditions. The aim was limited to assessing whether the results found in this limited study can be considered to fall within the distribution of the data found in the much larger study in the Netherlands.

The operational practice in pig production in Ireland is different in a number of aspects from practices in the Netherlands, as are the environmental conditions, see also section 7. These differences are not likely to cause significantly different odour emissions. Of course it would be preferable to have emission factors specifically obtained for Irish conditions. However, if reliable specific emission factors for Irish production practice are required, a much larger programme of odour emission measurements is required.

The case studies were conducted at three sites, and the characteristics summarised below:

- Case A: a large integrated pig unit, with approximately 1000 sows in fully slatted pig houses
- Case B: a medium sized integrated pig unit, with approximately 590 sows in fully slatted pig houses

The case study reports were prepared on the basis of information provided by the client, the Environmental Protection Agency and observations made during a site visit by the authors to the two farms in question. Odour samples were taken at representative locations and analysed at the Odournet odour laboratory in Bradford-on-Avon.

1.1.1 Study objectives

The study aimed to achieve the following objectives:

1. Assess the local situation during two site visits;
2. Determine appropriate sampling locations and numbers;
3. Collect samples and analyse in the Odournet UK laboratory.
4. Compare these the measured emissions in this limited sample relative to the distribution of results of the Dutch data. These have been used as the basis of emission estimates in the general background study.
5. Estimate the potential impact of the pig production units on any nearby residential properties;
6. Identify financially viable options for reducing the odour impact of the production units.

2. Detailed description of approach and methodology

2.1 Approach

This study can be regarded as having two distinct aims:

1. Limited measurement of emission rates to assess whether results in Ireland lie within the range of data from a larger study in the Netherlands

2. Detailed odour emission estimate and odour dispersion model study for each of the two farms

The results of these distinct parts of the study will be discussed in separate sections in the Results section

2.2 Limited measurement of emission rates for pigs

2.2.1 Objectives and approach to sampling

The purpose of the sampling was principally to collect data for comparison with odour emissions rates measured at similar pig units in the Netherlands. As the contribution of fatteners to the total odour emissions is the largest, during the rearing process, odour sampling was principally concentrated within fattening houses.

In addition a limited number of samples was collected to determine the emission rate from external uncovered sludge storage facilities.

The sampling took the following relevant factors into account:

- **Sample timing** - One day of sampling was carried out at each of the two farms. At each farm samples were taken from several groups of fatteners. The groups varied from one another in age and consequently average live weight of each group.

- **Time of the day** - Due to the necessity to collect all number of samples within one day, and transport the samples for analysis the following day, sampling was carried out between 07.30am and 3.00pm.

- **Ventilation** - The ventilation rate was measured at regular intervals during the collection of each sample. The velocity within each extract duct from the room being sampled was measured using a hot wire anemometer. A number of the ducts were fitted with large manually adjustable dampers, these resulted in uneven airflow through the ducts and made precise measurement difficult to achieve.

- **Other Parameters** - Ambient temperature and wind speed/direction were recorded at each site.

2.2.2 Odour sampling and analysis

Odour concentration was determined according to the EN13725 *Odour concentration measurement by dynamic olfactometry*[11] and results expressed in odour units ($ou_E \cdot m^{-3}$).

2.3 Detailed odour impact assessment for the two farms

Initially a model of the sources was constructed on a geographic information system (GIS), using:

- Site plans,

- Waypoints logged onto a portable Global Positioning System (GPS)

- Digitised Ordnance Survey 1:50,000 maps (provided by the Irish EPA)

Then the emissions for each building on the farms were estimated on the basis of the number of animals and their size and age, using emission factors that were established on the basis of extensive measurements in the Netherlands[5, 10].

Using the estimated emission rates, a source characterisation model was constructed and used as input for an atmospheric dispersion model. Combined with additional input data, such as hourly meteorological data for a nearby station, and digitised terrain data (topography), the model was constructed and applied to establish a first estimate of the environmental impact with regard to odorous emissions. As in the other studies, meteorological data were used for the station located at Claremorris, covering the period 1993 to 1995 (inclusive).

The COMPLEX-1 atmospheric dispersion model was used, as described in the next section. The model produces a probability of exceeding a certain hourly average concentration, at locations where people may be exposed.

When an annoyance criterion is applied to these results, a contour can be plotted which contains the area in which odour annoyance may occur.

A discussion on how the results of odour dispersion modelling should be interpreted is included in section 2.3.3 below.

2.3.1 The dispersion model used: Complex-I

COMPLEX-1 is an air pollution dispersion model, which can be used for estimating air pollutant concentrations in complex terrain. It was originally developed in the United States by the Environmental Protection Agency (EPA).

Complex terrain models are normally applied to stationary sources of gaseous pollutants (like SO_2) and particulates. The model is based on the so-called Gaussian plume model and it can be used to calculate one-hour to twenty-four-hour averaged concentrations at specific receptor points in a complex topography. The receptor points may be situated below as well as above stack height.

COMPLEX-1 is based on the MPTER model[27] and incorporates the plume impaction algorithm of VALLEY. With COMPLEX-1 computations can be made for up to 250 point sources and 180 receptors located within 50 kilometres of the sources[26].

MPTER is most applicable for source-receptor distances less then 10 kilometres. It can be used in rural as well as in urban areas, with flat or rolling terrain where a single wind vector for each hour adequately approximates the flow over the source and receptor sites. The Terrain adjustment option of MPTER is limited to receptors whose elevation is no higher than the lowest stack top elevation of the sources considered.

COMPLEX-1 is a modification of the MPTER model that incorporates the plume impaction algorithm of the VALLEY model. As a result COMPLEX-1 can also calculate ambient concentrations in situations where MPTER is not applicable, i.e. at receptors situated at a level above stack height.

The COMPLEX-1 model calculates and summarises the individual contribution to the overall emission pattern of each source, for each hour, at each point in the receptor grid. This summarised data can then be plotted as contours of equal odour exposure on a topographic map.

2.3.2 Methodology: Construction of the model of emissions and atmospheric dispersion

The following scenarios are modelled within this study for Farm A and Farm B:

- *Scenario 1*: Represents the actual existing situation at the farms, with mechanical ventilation. Modelling will encompass ventilation rates based upon those measured on the day of survey - which will not be equivalent to those under different climatic conditions. Emissions will be through the roof vents at a height of approximately 4m.

- *Scenario 2*: The situation will be as scenario 1, but assuming an abatement of 50% (utilising best practice techniques).

The COMPLEX-1 dispersion model requires 3 distinct types of input data to run:

- Data concerning the location, physical dimensions, frequency of activity and odour emission of the source.

- Local meteorological data.

- Local topographic data.

2.3.2.1 Odour source data

Odournet UK have identified and included all relevant sources in the odour emission model. Emission rates for each building were estimated on the basis of the number of animals housed and their life stage, using emission factors as proposed in the main EPA odour impact study document, that were derived from a large scale Dutch study[5, 10], summarised in an Annex, section 7 of this report. These data were used to construct a model of the source emissions providing the input data for odour dispersion modelling.

2.3.2.2 Meteorological data

The COMPLEX-1 model requires hourly averaged values for wind speed, wind direction and height of the mixing layer. The mixing layer height enables the atmospheric stability to be classified into one of six `Pasquill' categories, ranging from very stable to very unstable. Unstable conditions are the most favourable for dispersion of odours in the atmosphere.

Hourly meteorological data for the years 1993 to 1995 (inclusive) recorded at Claremorris were used for the modelling exercise.

2.3.2.3 Topographic data

We often refer to this as receptor data as it describes the location of receptors potentially exposed to odours. It consists of an X,Y,Z grid with an additional parameter H referring to the height of the receptor above ground (i.e. nose height).

2.3.3 Interpretation of odour modelling output data

The results of the modelling are presented in the form of contours or isopleths (lines connecting equal frequency of occurrence) for: 1.5, 3 and 6 ou_E/m^3 as a 98 percentile. These contours describe the area associated with the following proposed air quality criteria:

- **Target value: $C_{98,\ 1\text{-hour}} < 1.5\ ou_E \cdot m^{-3}$**
  The target value provides a general level of protection against odour annoyance for the general public, aiming to limit the percentage of people experiencing some form of annoyance to 10% or less. The target value shall be used as an environmental quality target for all situations.

  The target value is achieved when the calculated odour exposure for all locations of odour sensitive receptors is less than an hourly average odour concentration of 1.5 $ou_E \cdot m^{-3}$ in 98% of all hours in an average meteorological year.

- **Limit value for new pig production units: $C_{98,\ 1\text{-hour}} < 3.0\ ou_E \cdot m^{-3}$**
  The limit value for new pig production units provides a minimum level of protection against odour annoyance, aiming to limit the percentage of those experiencing some form of annoyance to 10% or less in a the general public, assuming some degree of acceptance of the rural nature of their living environment.

  The limit value for new pig production units shall not be exceeded in the vicinity of new pig production units to ensure a minimum environmental quality.

  The limit value for new pig production units is complied with when for all locations of odour sensitive receptors the calculated odour exposure is less than an hourly average odour concentration of 3.0 $ou_E \cdot m^{-3}$ in 98% of all hours in an average meteorological year.

- **Limit value for existing pig production units: $C_{98,\ 1\text{-hour}} < 6.0\ ou_E \cdot m^{-3}$**

  The limit value for new pig production units provides a minimum level of protection against odour annoyance, aiming to limit the percentage of people experiencing some form of annoyance to 10% or less, in the most tolerant selection of the population.

  The limit value for existing pig production units shall not be exceeded in the vicinity of existing pig production units to ensure the minimum environmental quality in an agricultural setting. A phased plan must be made to reduce the odour impact, with time, to the target value.

  The limit value for new existing production units is complied with when for all locations of odour sensitive receptors the calculated odour exposure is less than an hourly average odour concentration of 6.0 $ou_E \cdot m^{-3}$ in 98% of all hours in an average meteorological year.

These criteria are proposed in the main study prepared for the EPA, and are underpinned by actual dose effect relationships established on the basis of the percentage of residents annoyed, as determined by telephone survey[3].

The modelling results cannot be assumed to be an exact mirror of reality. The model will be less effective in predicting the actual exposure in a single hour, especially at distances to the source of less than 100 m. The models are more effective in predicting the probability of exposure levels over a large number of hours, such as the four-year data set of hourly observations used for this study.

The contours represent the area where the maximum hourly average ground level concentration will be greater than 1.5, 3 or 6 $ou_E \cdot m^3$ for more than 2 % of the hours in the year.

The predicted ground level concentrations are *above* background concentrations and only relate to odour originating from the works.

2.3.4 Model of source: odour emission estimation

2.3.4.1 Assumptions used in determining odour emission rate

The following assumptions have been used to model the emissions for all scenarios.

- The odour concentration is homogeneous within the building.
- The numbers of pigs as provided by the farm representatives are accurate, and the animals are evenly distributed amongst the buildings as appropriate.
- The situations found during the site survey are representative of normal operation
- The movement of animals has not been modelled. For instance, transfer between buildings and delivery / dispatch.

3. Results

3.1 Farm A

3.1.1 Description of the study area: Farm A

Farm A is a large integrated unit with over 1000 breeding sows. The unit is not fully integrated, as a proportion of weaners and fatteners are moved of site for finishing elsewhere. The site manager provided a tour of the facilities. The site has eight separate fattening houses of traditional slatted floor type, with mechanical ventilation through roof fans. Each house is divided into three rooms, which are in turn subdivided into 12 pens containing an average 18 pigs each. In each room three fans draw air from one wall, fresh air is introduced via a perforated ceiling. All animals are fed liquid feed via a central distribution system.

Sows, gilts and farrowers are contained within separate slatted floor buildings. A number of these buildings have slurry tanks beneath the floors, whilst slurry from the dry sow house and gilt houses is stored in open top, concrete lined lagoons. All these buildings were ventilated by centrally mounted roof fans.

The operation was run to a high standard, and no clear operational flaws were observed. There is no history of registered odour complaints.

Slurries are tankered off site for land spreading. Tankers draw slurry directly from either the above ground lagoons or the under floor storage tanks. It is not normally necessary to agitate or stir any of these tanks prior to removal of slurry. During the visit the open lagoons were mostly full.

Table 1: Estimated numbers of animals for Farm A

Life stage	Number of animals
Weaners	6210
Farrowers	90
Dry sows	1072
Fattening pigs	10408
Gilts	172

3.1.2 Site visit observations Farm A

A site visit was carried out on Monday 17th April 2000 by Matthew Houseman (Odournet UK Ltd.) and Margarethe Bongers (PRA bv). The sampling program was undertaken on the 18th of April 2000 by Matthew Houseman and Matthew Stoaling (Odournet UK Ltd.). During the visit to Farm A on the 17th April odour was faintly detectable for a distance of approximately 50 metres across fields at that time downwind of the site.

Sampling was carried out at Farm A on the 18th April on a clear and bright day, with temperatures averaging 15ºC. There was a gentle breeze from the north west (up to 2.5 m/s). Operations at the site were normal with a tanker intermittently removing slurry from the tank beneath one of the fattening houses.

Image 1 - A fattening house at Farm A - the primary unit type at this facility

3.2 Farm B

3.2.1 Description of Farm B

Farm B is an integrated production unit with approximately 590 breeding sows. All production takes place within one site.

Weaners are raised in groups of 160 in slatted floor rooms with a single centrally mounted ventilator in each room. Fattening then takes place in rooms of twelve pens, with approximately 250 pigs per room. The fattening rooms are also mechanically ventilated with two centrally mounted fans in each room. Final finishers of approximate 90 kg live weight are kept in smaller groups of approximately 36. These groups are in smaller stalls with sidewall mounted mechanical ventilation. All pigs at Farm B are fed with a dry blended feed.

The operation was run in a professional manner, and the site was kept clean and tidy. There is no history of registered odour complaints.

Slurries are usually stored in underground tanks beneath the slatted floors. Tankers take slurry from land application directly from these tanks. An additional circular, open topped storage tank is available. However due to the low density of pig units in the vicinity of Farm B finding land for spreading is not usually difficult and hence the tank is rarely in use.

3.2.2 Site visit observations Farm B

A site visit was carried out on Monday 17th April, 2000 by Matthew Houseman (Odournet UK Ltd.) and Margarethe Bongers (PRA bv). The sampling program was undertaken on the 19th of April 2000 by Matthew Houseman and Matthew Stoaling (Odournet UK Ltd.). No odour was detectable off site from Farm B on the 17th April.

Table 2: Estimated numbers of animals for Farm B

Life stage	Number of animals
Weaners	2964
Suckling sows with piglets	114
Dry sows	479
Fattening pigs	2192
Gilts	101
Boars	18

Sampling was carried out at Farm B on the 19th April as heavy rain crossed Southern Ireland, with outside temperatures falling to 8˚C at the end of the sampling. There was a strong wind from the south west (up to 6.5 m/s).

Operations at the site were normal with no sludge removal operations taking place.

3.3 Odour emission measurements

In order to simplify the practice of producing a detailed odour study for farms in Ireland, the use of emission estimates based on emission factors per animal has been proposed in this document. The most recent and detailed study regarding pig emission factors was identified, to form the basis for these emission factors. The emission estimates were derived from data collected in a study commissioned by the Ministry of Public Planning and the Environment in the Netherlands, and carried out by

Image 2 - The fattening houses at Farm B. The centrally mounted extraction vents can be clearly observed.

the Institute for Agricultural Engineering IMAG-DLO in Wageningen[5].

A detailed account of the approach and methodologies used in the IMAG-DLO study is available in annex 7 of this report. In general, the methods employed when sampling from the two Irish farms were as close to those used in the Dutch project as possible. However, due the variable nature of the construction of pig housing, and conditions, some assumptions were made. These are also outlined in annex 7.

It was decided to conduct the measurements in Ireland for one housing type only, so the statistical uncertainty could be limited within the given scope of the sampling programme. As the primary sources of odour at an integrated unit are the fattening houses, all samples were taken within these buildings. The results of the measurements in Ireland were compared with the Dutch data for all housing types. In order for the Irish samples to be comparable to those collected in the Dutch study, the protocols used in the Dutch study were followed wherever practicable.

3.3.1 Description of sampled pig units and conditions during sampling

All fatteners sampled within the two Irish case study farms were housed within slatted floor buildings equipped with mechanical ventilation. The number of pigs per room varied from 36 to 260.

- **Floor area and animal places** - Floor area per pig varied depending upon animal weight, but was in line with Irish Animal Welfare Regulations (Note: these are currently only applicable to new pig units).

- **Feed** - Pigs were fed a liquid feed at Farm A and a dry feed at Farm B.

3.3.1.1 Sampling at Farm A

Sampling was carried out at Farm A on the 18th April on a clear and bright day, with temperatures averaging 15˚C. There was a gentle breeze from the north west (up to 2.5 m/s). Operations at the site were normal with a tanker intermittently removing slurry from the tank beneath one of the fattening houses.

Three samples were taken at each point. The surface of the lagoon was sampled twice, and one sample of ambient air was collected. Samples in the pig units were typically taken within the central passageway of each pig house at a height of 1.5 metres above the slatted floor. Each sample took approximately 30 minutes to collect. Samples were collected between 08.00 and approximately 16.00 hours.

No sampling took place during the feeding of pigs. During sampling the air flow velocity of each fan within the particular room was measured. At least five measurements were taken per fan. During the fan measurements the percentage of fan capacity employed was recorded from the display on the ventilation control units.

3.3.1.2 Sampling at site B

Sampling was carried out at Site B on the 19th April as heavy rain crossed the area, with outside temperatures falling to 8˚C at the end of the sampling. There was a strong wind from the south west (up to 6.5 m/s).

Operations at the site were normal with no sludge removal operations taking place.

Odour sampling was principally concentrated within fattening houses. Three samples were taken at each point. Samples were typically taken within the central passageway of each pig house at a height of 1.5 metres above the slatted floor. Each sample took approximately 30 minutes to collect. Sampling took place between 07.30 and approximately 15.50 hours.

No sampling took place during the feeding of pigs. During sampling the air flow velocity of each fan within the particular room was measured. At least five measurements were taken per fan. During the fan measurements the % of fan capacity employed was recorded from the display on the ventilation control units.

3.3.1.3 Number of samples

Twelve samples were taken from fattening pigs housing at each farm. This represented triplicate samples from four groups of fatteners at each farm.

In addition an ambient sample and two samples from the surface of a slurry lagoon were taken at Farm A and three samples from a weaner house at Farm B. Therefore of the 31 samples taken, 24 were directly aimed at the comparison with emission rates as determined in the Netherlands.

3.3.2 Results of emission rate measurements

The results of the measurements of odour emissions, carried out on site A and site B, are presented in Table 3. The emission factors per animal (in ou_E/s per animal place) were calculated by multiplying odour concentration (ou_E/m^3) with ventilation rate (m^3/s) per animal place, to obtain an emission rate in ou_E/s per animal.

For each sampling location, the geometric mean of the replicate samples was calculated.

The overall emission for a finisher was calculated as the median value of all measured emission factors for finishers of all weights, giving an emission rate of 15 ou_E/s per animal place at an average ventilation rate of 50 m^3/h per animal. The geometric mean was 13.2 ou_E/s per animal

For weaners, only one emission rate was obtained, on the basis of triplicate samples, with a value of 2.8 ou_E/s per animal place.

In addition to the measurements in the pig houses, a sample was collected of ambient air on the lee side of Farm A. The odour concentration was below the detection limit of 40 ou_E/m^3 as expected.

Two samples were collected using a Lindvall hood for sampling area sources. The flow velocity under the hood was 0.39 m/s. The specific emission rate calculated on the basis of the geometric mean of the results of 2813 ou_E/m^3 is 31 $ou_E/m^2/s$.

3.3.3 Discussion of emission measurement results

The median emission rate measured in this limited study in Ireland, of 13.2 ou_E/s, is approximately one third lower than the value of 22.6 ou_E/s per fattening pig that was the result of the study in the Netherlands[5,10] (see summary of that research in annex 7).

The difference is considerable, but not sufficiently large to conclude that the observations obtained in Ireland are significantly different. The observed difference would fall within the statistical variability between farms and within farms that was found in the study in the Netherlands[5].

Table 3: Emission rates for finishers and weaners, calculated from measured odour concentration and ventilation rates per finisher measured at site A and B, Ireland, April 2000.

Stage	Odour concentration sample a ou_E/m^3	sample b	sample c	Geomean	ventilation rate m^3/s	No of fans per room	% of max. fan capacity	Odour emission rate ou_E/s	No. of animals	Emission rate per animal ou_E/s
Site A										
Fatteners 35 - 40 kg	1499	1914	262	909	3.9	3	45%	3546	216	16.4
Fatteners 70 kg	1483	1394	679	1120	3.9	3	44%	4367	216	20.2
Fatteners 90 kg	764	n/a	379	538	3.0	3	37%	1587	216	7.3
Fatteners 50 kg	1073	n/a	1345	1201	2.8	3	34%	3364	216	15.6
Site B										
Fatteners 70 kg	961	1450	1508	1281	3.0	2	21%	3868	262	14.8
Fatteners 40 kg	2243	1641	1505	1769	2.7	2	18%	4777	256	18.7
Fatteners 60 kg	862	908	731	830	3.2	2	24%	2640	239	11.0
Fatteners 90 kg	403	289	1498	559	0.5	1	n/a	279	36	7.8
Weaners 40 kg	779	549	400	555	0.8	1	43%	455	164	2.8

Table 4: Results of odour analysis of measurements of ambient air and of samples collected from a Lindvall hood over sludge storage at Farm A.

Analysis datafile	Sample ID	Date of analysis	Odour concentration [ou_E/m^3]	Panel size	Valid ITE's	Remarks
00041913	Ambient air	19/04/2000	<40	--	--	Below lower detection limit, not valid under CEN prEN 13725
00041915	Slurry Lagoon	19/04/2000	3465	5	8	Geomean = 2813 ou_E/m^3
00041916	Slurry Lagoon	19/04/2000	2283	5	10	

In the Dutch study, a total of 80 samples were collected over a longer period of time. The geometric mean of odour emission from the fattening pig system amounted to 22.6 ou_E/s per finisher place at a mean ventilation rate of 33.3 m^3/h per animal[5,10]. The estimated variance components in that study, expressed as variation coefficients (or the standard deviation as a percentage of the mean value), for fattening pigs were:

- Between farm variation: 22%
- Within farm variation: 34%
- Variation between duplicate samples: 16%

The within farm variance is the largest component and is about two times larger than the between farm variance.

Sampling in Ireland was carried out on two days, under weather conditions that cannot be described as *summer conditions*. The ventilation per animal in Ireland was relatively high, compared to the ventilation rate observed in the Netherlands. Both factors will tend to lead to lower emission rates.

The odour concentration measured in the ventilation air is higher than the values measured in Ireland in 1989 by Carney and Dodd[21], which ranged between 20 and 40 dilutions to threshold. However, it must be noted that the olfactometry utilized in that research did not comply with any of the national or international standards that have been introduced since that time. Increases of an order of magnitude in the value of odour thresholds measured by laboratories since the introduction of odour units traceable to reference odours have been reported in other instances[18].

The measured specific emission rate of 31 $ou_E/m^2/s$ is relatively low for a sludge basin. Sludge emission rates can vary considerably, depending on the conditions that determine the microbial degradation of the sludge, such as oxygen availability and temperature.

OdourNet would expect the summer emissions from the sludge to be an order of magnitude higher.

Emission rates are significantly increased when the sludge is turbulent, through handling or stirring. Turbulence can cause emissions to increase by an order of magnitude again compared to a still surface.

3.4 Odour emission scenarios

3.4.1 Odour emission scenarios Farm A

The emissions from Farms A were estimated using the data resulting from the Dutch larger scale study[5,10], see Table 5 overleaf. These estimations were used as the basis for the atmospheric dispersion modelling scenarios.

3.4.2 Odour emission scenarios Farm B

The emissions from Farm B were estimated using emission factors as proposed in the larger EPA study on the basis of the data from a larger scale Dutch study[5, 10], see Table 6 overleaf. These estimates were used as the basis for the atmospheric dispersion modelling scenarios.

Table 5: Estimated numbers of animals and their odour emissions from Farm A

Estimated odour emission rate from Farm A	Number of animals	Emission rate in ou_E/animal/second	Emission rate, [ou_E/s]	Emission rate [10^6 ou_E/hour]	Percent of total
Weaners	6,210				
Farrowers	90				
Dry Sows	1,072				
Gilts	172				
Subtotal excluding fatteners			62,649	226	21%
Fattening pigs	10,408	22.6	235,221	847	79%
Total	**17,952**		**297,870**	**1,073**	**100%**

Table 6: Estimated numbers of animals and their odour emissions from Farm B

Estimated odour emission rate from Farm B	Number of animals	Emission rate in ou_E/animal/second	Emission rate, [ou_E/s]	Emission rate [10^6 ou_E/hour]	Percent of total
Weaners	2,964				
Suckling sows with piglets	114				
Dry Sows	497				
Gilts	101				
Boars	18				
Subtotal excluding fatteners			31,676	114	39%
Fattening pigs	2,192	22.6	49,539	178	61%
Total	**5,886**		**81,215**	**292**	**100%**

4. Discussion of the results of Atmospheric Dispersion modelling of the existing situation

Note: *For guidance on interpretation of the odour contours, refer to section 2.3.3.*

The results of the model run for the two scenarios are discussed below. The contour lines indicate the area in which the limit value values of target value $C_{98,\ 1\text{-hour}}$ = 1.5 ou_E/m^3, the limit value for new pig units in Greenfield sites $C_{98,\ 1\text{-hour}}$ = 3ou_E/m^3 and the limit value for existing pig units of
$C_{98,\ 1\text{-hour}}$ = 6 ou_E/m^3 will be exceeded.

- In reality, the case studies all concerned existing pig units, so that the limit value should be applied. The target value should be regarded as a long-term goal.

The $C_{98,\ 1\text{-hour}}$ indicates that the limit concentration is exceeded during 2% of the 8760 hours in an 'average year'. This equals approximately 175 hours.

4.1.1 The situation at Farm A

The results of the model run for the existing situation, Scenario 1, are presented in a figure, annex 9.1. The contour for the limit value $C_{98,\ 1\text{-hour}}$ = 6 ou_E/m^3 extends for considerable distances, of over 1 km from the farm buildings. Given the location of the farm, the number of dwellings affected is limited. OdourNet does not have access to a detailed survey of the dwellings in the vicinity, nor their use. From the map it would appear that ten dwellings are within the limit value contour. These may be farmhouses, in which case it can be argued that these dwellings can expect a more lenient level of protection, in the absence of complaints. To achieve a more acceptable situation, however, the emissions from Farm A should be reduced in the long term.

When a 50% reduction of emissions is achieved, the odour impact of Farm A is significantly reduced. The number of dwellings indicated on the map that lie within the limit value contour is reduced to two, see the map in Annex 9.2. These dwellings are quite close to the limit value of the contour. It is likely that optimisation of ventilation, in combination with a 50% odour emissions reduction, would reduce the odour footprint so far as to not include any dwellings.

The area in which the impact is such that the target value of $C_{98,\ 1\text{-hour}}$ = 1.5 ou_E/m^3 is exceeded does include a significant number of approximately 100 dwellings, even for Scenario 1.

The overall implication is that for Farm A reductions are feasible that would enable continuation of operations at the current site, when exposure in excess of the target value is deemed acceptable. There is, however, a need to reduce emissions to bring exposure within the limit value. The options for an increase of production levels at the site of farm A are not easily attained, without more drastic odour control measures that are not generally considered financially viable at current market conditions.

4.1.2 The situation at Farm B

The results of the existing situation at Farm B, modelled in Scenario 1, are presented in a figure, annex 9.3. The contour for the limit value $C_{98,\ 1\text{-hour}}$ = 6 ou_E/m^3 extends for relatively modest distances, of less than 500 m from the farm buildings. OdourNet does not have access to a detailed survey of the dwellings in the vicinity, nor their use. From the map it would appear, however, that four dwellings are located within the limit value contour.

The area in which the impact is such that the target value of $C_{98,\ 1\text{-hour}}$ = 1.5 ou_E/m^3 is exceeded does include a significant number of dwellings (nine).

Although in the short term no odour emission reduction would be required, a reduction should be the aim when replacing assets, by using specifically low-emission housing systems. These can achieve a 50% reduction of emissions. The situation that would arise as a result of such a reduction is shown on the map in Annex 9.4. In this situation, the contour representing the target value ($C_{98,\ 1\text{-hour}}$ = 1.5 ou_E/m^3) is reduced to such a degree that four dwellings are affected

The overall implications for Farm B are limited, in that no immediate actions are required. The odour impact in the current situation is reasonably acceptable, given its rural context. To adhere to the proposed limit value limited abatement options can be considered, e.g. optimising the release of ventilation air by increasing height of release and vertical velocity. Continued attention to avoiding incidental releases caused by actions such as slurry loading is essential, especially when weather conditions are unfavourable, given the short distance to the nearest dwellings. In the long term low-emission housing is an option to be considered when replacing current housing assets, with a view to attaining the target value and, potentially, creating options for growth of stock numbers in this location.

5. Options for reducing the odour impact

The two pig production units surveyed in this study are similar in their design, and abatement options discussed here will apply to both, generally speaking.

There is one difference in that Farm A has a sludge storage and transfer unit, with a rectangular open buffer tank and a storage tank. This source will be discussed separately.

To reduce the odour impact from the pig production at current capacity levels there are fundamentally three options:

1. Reduce the emissions by modification of production method and type of pig housing units

2. Reduce the emissions by collection of ventilation air followed by treatment in an odour abatement unit

3. Reduce emissions by good operational practice - especially storage of slurries at Farm A

4. Reduce emissions by reducing production capacity

5.1 Operational practice

Although farms are already aware of operational requirements for reducing odour emissions through appropriate cleaning, covering of skips, etc., there were still many adaptations that could be made to the operational practice that would have a significant effect on the odour emitted. For instance, at Farm A, the carcass skip was not housed in an appropriate building or covered (see image 3, below). A simple and cheap cover, and regular emptying, would result in emissions from this source being dramatically reduced.

The risk of causing annoyance may be reduced by carefully planning actions on the farms and related to land spreading. Odournet UK recommends:

- Suspend sludge transfer operations in unfavourable conditions (low winds in summer conditions in the direction of the closest residences)

- Avoid land spreading in the vicinity to reduce odour impact associated with the farm operations, especially in dry weather or summer conditions

5.2 Modification of production method

A modification that could be implemented in the short term at Farm A, is an overhaul of slurry storage practice. Images 4 and 5 show the current situation. There are a number of options available for sludge storage that reduces emissions.

Modifications may include:

- Collection of slurry in closed tanks, followed by anaerobic digestion.

  In this process the odourants that are produced can be destroyed by controlled incineration of the biogas.

Image 3 - An uncovered carcass skip is a source with a high potential to cause annoyance in summer conditions.

The digested slurry is significantly less odorous, which is a great benefit when spreading

- Covering the surface
  - i. Natural crusting
  - ii. Floating biological covers (straw, fibre)
  - iii. Floating covers (rigid or custom designed foil covers)
  - iv. Liquid additives (vegetable oils)

These methods are covered in detail in the associated report *'Part A Odour annoyance assessment and criteria for intensive livestock production in Ireland'*

A longer-term solution to reduce emissions would be modification of the production method. Replacing the current fully slatted system with low-emission pig housing, such as the so-called 'green label' buildings that haven been introduced in the Netherlands. Using these housing systems can potentially reduce emissions to 50% of the current levels[24, 30]. Such a replacement would be feasible only when planned within the normal cycle of asset replacement.

5.3 Collection of ventilation air and odour control treatment

To be able to apply odour abatement techniques to the current installations, the ventilation air that is now released via roof ventilators would need to be collected and ducted to a central point for treatment in an odour control unit for each building. The scale of each farm would deem the ducting of all air to a central unit as financially inhibitive.

Due to the fluctuating nature of the ventilation rates, as determined by the temperature in the houses, each exhaust would be required to retain regulating mechanism. Ducting would require a significant capital investment. However this would be less than the installation of multiple abatement units.

Once the air can be ducted to a central point on each building for treatment there are a number of options for reducing the odour concentration in the exhaust air.

These options include:

1) Release of all extracted air through an elevated stack.

Image 4 - The slurry is open to the ambient air and is frequently disturbed

Image 5 - The main slurry storage tank covers an area of over 1000m2

Image 6 - Roof ventilation at Farm A

Image 7 - Roof ventilation at Farm B

This can achieve significant reduction of ground level concentrations through enhanced atmospheric dilution

2) Odour abatement through treatment by:
   a) Chemical scrubbing
   b) Biological scrubbing
   c) Biofiltration, potentially combined with pre-treatment for H_2S using a catalytic iron filter
   d) Biofiltration on fixed medium substrate covered with a biofilm, such as a lava-rock filter.

These treatment techniques are described in detail in the associated reports. These techniques all have the potential to reduce the odour concentration in the ventilation air significantly, with a reported efficiency of up to 90 to 95%.

After treatment the treated ventilation air could be released from a raised stack, to further reduce the odour impact by achieving atmospheric dilution. Increasing the velocity of the exit air will also increase this effect. This approach is a costly but effective solution. The quantities of ventilation air are considerable, and determined by the ventilation needs of the animals. Assuming a ventilation rate of 0.5 m^3/kg pig/hour the total estimated ventilation flow rate for Farm A would be 524,000 m^3/hour.

Treatment options are not considered in detail in this report, as the associated cost is prohibitive under current market conditions.

6. Conclusions

6.1.1 Conclusions on the results of finisher emission rate measurements in Ireland

The geometric mean emission rate of 13.2 ou_E/s per finisher measured in Ireland for this study is about one third lower than the value of 22.6 ou_E/s per finisher found in a larger study in the Netherlands.

Given the relatively small number of samples, collected in the Irish study, and the statistical variance as derived from the larger Dutch study, the difference in the mean outcome is too small to be statistically significant.

Therefore, it is justified to use the emission factors derived in the Netherlands for emission estimates in Ireland, as long as emission factors specifically measured in Irish conditions are not available for a larger sample of study sites.

6.1.2 Odour impact study Farm A

Farm A is a large integrated unit, containing over 17000 animals. It is therefore no surprise that total emissions are high, and the odour footprint relatively large. However, given the locality of the farm - it's distance from residential units and it's rural context, there seems to be no urgency as no complaints have been registered. The only concerns resulting from the site visits were the uncovered slurry store and carcass skips. It is the opinion of Odournet UK that these sources may become a significant emitter of odours during the warmth of summer. However, having undertaken sampling during a cool spring day, there is no quantitative data to support this.

The modelling shows that in the current situation a limited number of (ten) dwellings may be affected by odour impacts in excess of the limit value. It is therefore necessary to seriously consider options to reduce emissions. In the short-term measures to reduce emissions from sludge storage should be considered. In the longer term, replacement of housing assets could reduce the number of dwellings exposed to odour impacts in excess of the limit value, conceivably to zero. The target value will be difficult to attain for farm A. The farm can be made sustainable at current stock levels, from the perspective of odour impact, provided that the community recognises and accepts the rural context in the vicinity.

6.1.3 Odour impact study Farm B

Farm B is a relatively small-scale operation. Under current circumstances, the odour footprint includes four domestic dwellings within the limit value contour. This farm may require the installation of abatement options. However, this would not be critical if current stock numbers and good practice are maintained. Continued attention to avoiding incidental releases caused by actions such as slurry loading is essential, especially when weather conditions are unfavourable, given the short distance to the nearest dwellings.

In the long term, a reduction of odour emissions should be considered when normal renewal of housing assets becomes an issue. This could achieve attainment of the limit value for all dwellings in the vicinity and, potentially, create room for some growth of stock when the agricultural context of the area is recognised and accepted as the status quo.

7. Annex: Summary of large-scale survey to establish pig odour emission factors in the Netherlands.

7.1 Background

The regulatory system in the Netherlands to control odour nuisance from agricultural sources, uses the ‘mestvarkeneenheid’ or MVE (literally ‘fattening pig unit’) as the basic emission unit for livestock emissions. One MVE represents the odour emission from one fattening pig place in a traditional housing system with a fully slatted floor and slurry storage tanks beneath the slats.

In the Netherlands, fattening pigs are defined as boars from about 25 kg till 7 months (final live weight between 90 and 120 kg) or sows from about 25 kg till their first cover.

Odour measurements were carried out by the Institute of Agricultural and Environmental Engineering (IMAG-DLO) in a project funded by the Dutch government to establish an emission factor for the Dutch pig unit into standardised odour units[5]. The measurements are based on an official Dutch measurement protocol (‘Meetprotocol voor geuremissies uit stallen’). For aspects of methodology the protocol refers to ‘Guideline for assessment of low ammonia emission housing systems’.

The housing conditions, sampling method and results are described below. The design of the sampling programme was derived from the guidance in the references listed below (the numbers between parentheses refer to the main list of references in this report):

- [5] Ogink, N.W.M., Klarenbeek, J.V., *‘Evaluation of a standard sampling method for determination of odour emission from animal housings and calibration of the Dutch pig unit into standardised odour units’*, Institute of Agricultural and Environmental Engineering (IMAG-DLO);

- Werkgroep emissiefactoren, *Meetprotocol voor geuremissies uit stallen (translated:Measurement protocol for odour emission from livestock operations)*, Ministry of Agriculture, Nature Management and Fisheries, The Netherlands, 1996;

- [24] *Beoordelingsrichtlijn in het kader van Groen Label Stallen (Guideline for the assessment of Green Label livestock housing systems)*, ed. 1996, Ministry of Housing, Public Planning and the Environment and the Ministry of Agriculture, The Hague, Netherlands, 1996.

7.2 Study sites selection and methodology

Four pig units were randomly selected by IMAG-DLO, each including substantial numbers of fattening pigs. To be suitable for the study the following features were required at each site:

- **Housing system** - The housing system should consist of mechanically ventilated compartments with pens equipped with partially slatted floors and slurry storage underneath.

- **Floor area and animal places** - Each pig in the final weight range should have at least 0.70 m^2 floor area of which a maximum 0.40 m^2 may be slatted. Animal places varied between sites from 80 to 130 pigs per compartment. The floor area is determined by the housing conditions required to meet animal welfare regulations.

- **Feed** - Pigs were fed standard feeds (starter feed and finishing feed) with protein and energy contents within prescribed ranges that are similar to those prescribed for ammonia measurements[24].

- **Sample timing** -Two successive fattening rounds were sampled, of which one round had to start in the second quarter of the year. In each round five odour samples were taken evenly distributed over the fattening period.

  At each production site the odour emission of a single compartment was measured. As one group of pigs is kept in one compartment during their fattening stage, the same pigs are sampled at five different stages.

- **Time of the day** - Samples were collected during two-hour periods between 10:00 AM and 12:00 AM only. These sampling periods were timed to coincide with relatively high odour emissions during the daily cycle. Two reasons support this choice. Firstly whilst emissions are known to be strongest around midday, variations in emission for the rest of a 24-hour day are not yet fully quantified. Second, strongest emissions will contribute most to odour nuisance.

- **Number of samples** - Samples were collected at each of the four study sites, in the course of five sampling sessions at each site, at different stage life cycle stages of a group of fatteners. As two groups of fatteners were followed sampling took place on ten discrete days per site. Each sample was taken in duplicate, giving a total of 20 samples per site, or a total of 80 samples for the four farms within the study.

  The required number of samples was defined by the statistical accuracy (uncertainty) per sample and by possible variation in emission during the year (seasonal differences). The timing of sampling was designed to follow the guidance provided in 'Beoordelingsrichtlijn Groen Label Stallen', in order to derive a representative yearly average.

- **Sampling method** - The samples were collected using the lung method. This requires odour sample bags to be placed within airtight containers. A vacuum is then applied to the airtight container, surrounding the sample bag. As the bag expands to fill the vacuum it draws odorous air into the bag via a tube from the site of interest.

  The evacuation rate was volume proportional to the ventilation rate of the fan (controlled by a critical orifice). The inlet of the sampling tube was located in the ventilation shaft before the fan. Both the sampling tubes and the containers were heated if necessary to avoid condensation. The odour bags remained in the container until analysis in the odour lab within 30 hours after collection.

- **Odour Analysis** - Odour concentration were determined according to the Dutch olfactometric standard method NVN2820:1995 and results expressed in Dutch odour units (ge/m^3). Please note that 1 ou$_E$/m^3 = 2 ge/m^3. This is a fixed proportion, caused by selecting assessors with an average detection threshold of 20 ppb/v n-butanol for NVN2820, while EN13725 selects using 40 ppb/v n-butanol.

- **Ventilation** - During sampling the ventilation rate was measured continuously by a fan wheel anemometer in the ventilation shaft.

- **Other parameters** - Temperature and humidity were measured in the compartment and outdoors by combined sensors.

7.2.1 Results

Odour emissions (ou$_E$/s per animal place) were calculated by multiplying odour concentration in ou$_E$·m^{-3} with ventilation rate (m^3/s) per animal place.

For sampling day the geometric mean of the duplicate samples was calculated. The average per facility was calculated as the geometric mean of the results from each sampling day.

The geometric mean of odour emission from the fattening pig system amounted to 22.6 ou$_E$/s per animal place at a ventilation rate of 33.3 m^3/h per animal.

The estimated variance components, expressed as mean percentage deviations, for fattening pigs were:

Between farm variation	:	22%
Within farm variation	:	34%
Variation between duplicate samples	:	16%

The within farm variance is the largest component and is about two times larger than the between farm variance.

8. Annex: References

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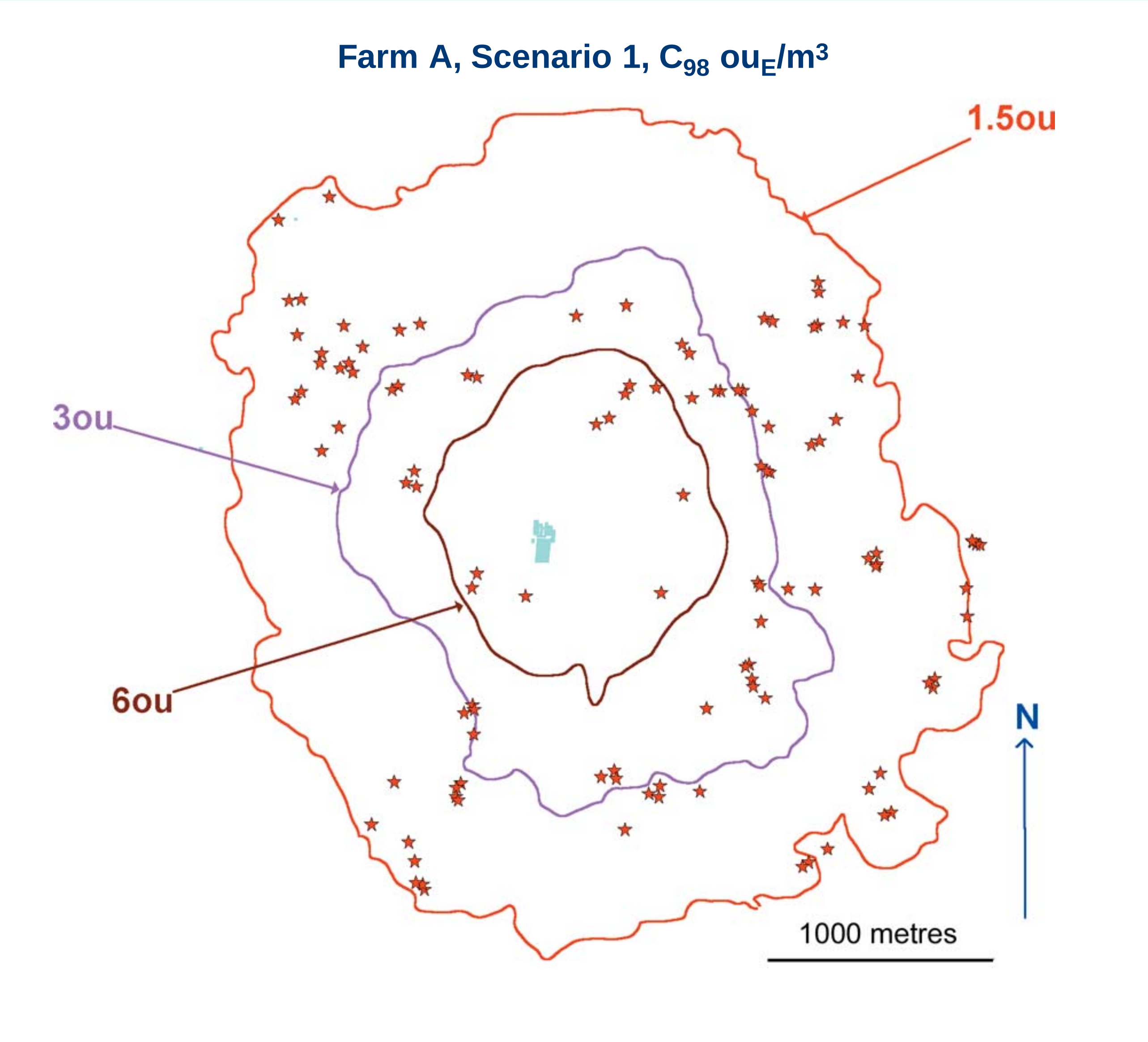
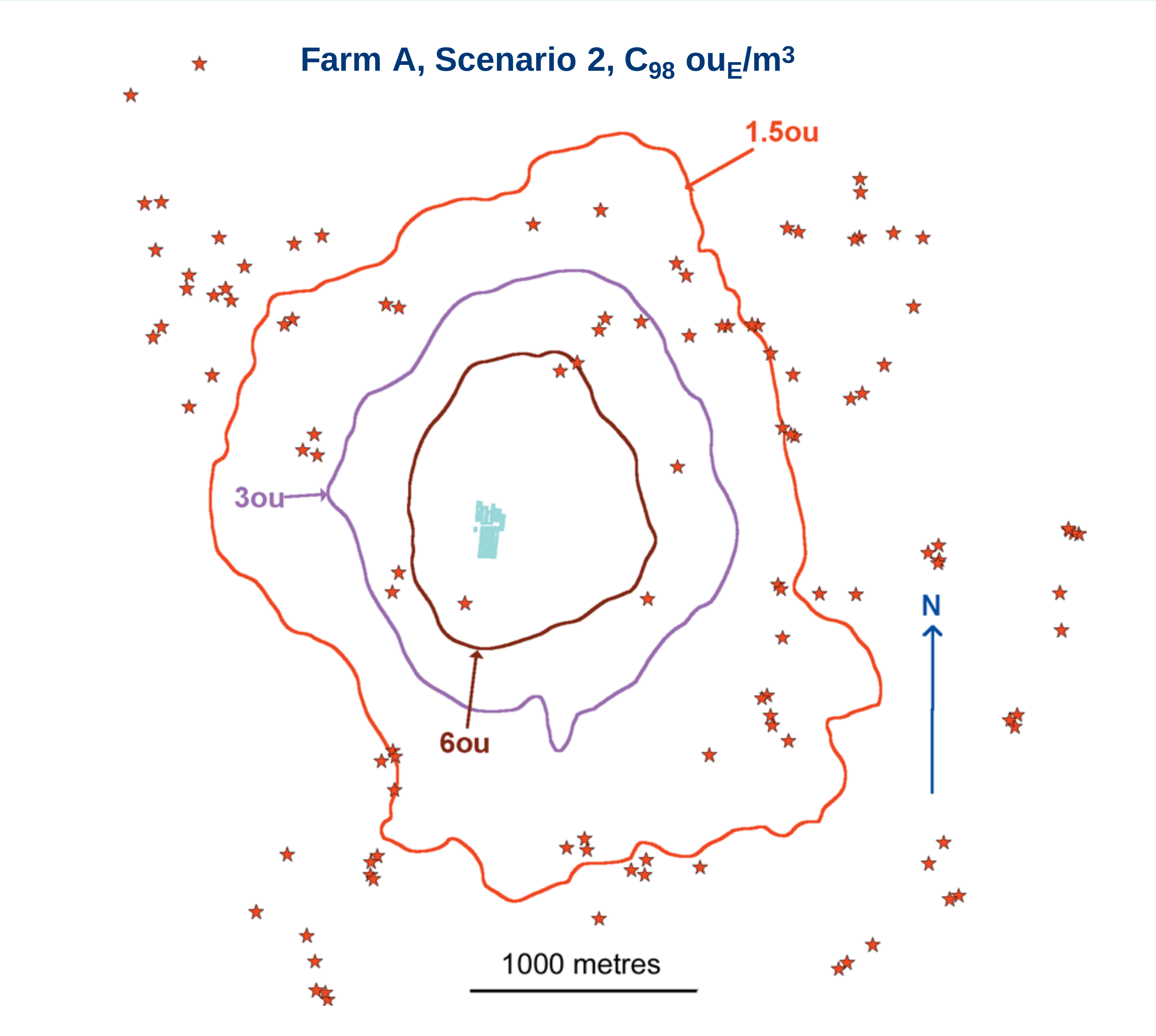
9. Annex: Figures

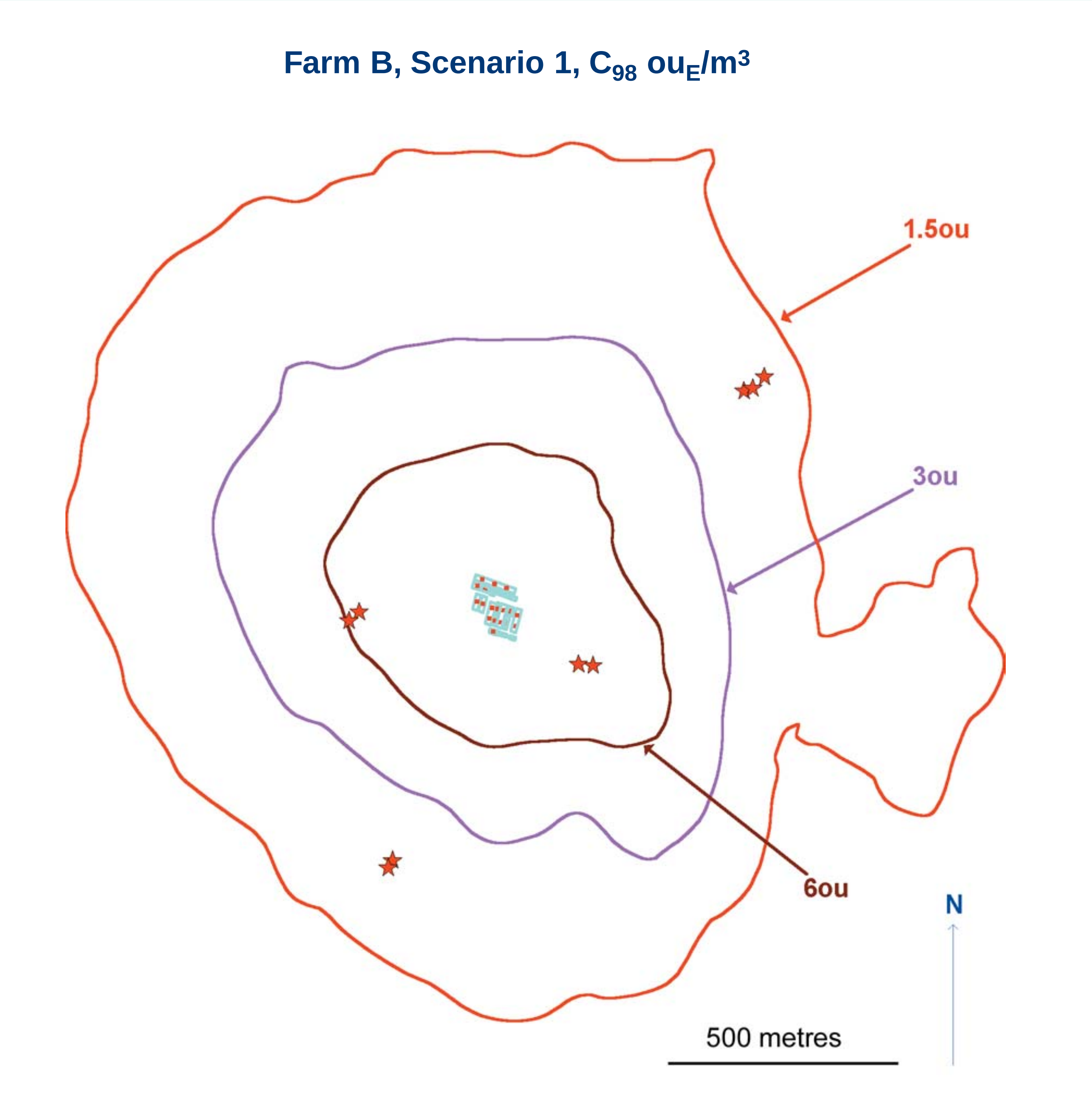
9.1 Scenario 1, Existing situation impact of farm A, mechanical ventilation, with vents modelled as point sources (residences referred to in text marked with stars)



9.2 Scenario 2, Farm A, mechanical ventilation, with vents modelled as point sources, after reduction of emissions by 50% after abatement (residences referred to in text marked with stars)



9.3 Scenario 1, Existing situation impact of farm B, mechanical ventilation, with vents modelled as point sources (residences referred to in text marked with stars)



9.4 Scenario 2, Farm B, mechanical ventilation, with vents modelled as point sources, after reduction of emissions by 50% after abatement (residences referred to in text marked with stars)