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**A dispersion modelling approach to determine the odour impact of intensive
poultry production units in Ireland**

E.T. Hayes^{a,b}, T.P. Curran^{a*}, V.A. Dodd^a.

^aDepartment of Biosystems Engineering, University College Dublin, Earlsfort Terrace, Dublin 2, Ireland.

^bCurrent address: Air Quality Management Resource Centre, University of the West of England, Bristol, Frenchay Campus, Coldharbour Lane, Bristol BS16 1QY, UK.

*Corresponding Author. Fax: + 353 1 4752119. Email: tom.curran@ucd.ie (T. Curran)

Abstract

The use of atmospheric dispersion modelling has become more common for the determination of odour impacts from existing poultry production facilities and the assessment of setback distances for new facilities. Setback distances for broiler, layer and turkey units were determined using the atmospheric dispersion modelling software ISCST3 and the Environmental Protection Agency (EPA, Ireland) recommended criterion ($C_{98,1-h} \leq 6.0 \text{ ou}_E \text{ m}^{-3}$) and a new odour annoyance criterion ($C_{98,1-h} \leq 9.7 \text{ ou}_E \text{ m}^{-3}$) developed in this study. For a typical size unit in Ireland; maximum setback distances of 660, 665 and 1035m were calculated for 40,000 broilers, 40,000 layers and 10,000 turkeys respectively at the current limit ($C_{98,1-h} \leq 6.0 \text{ ou}_E \text{ m}^{-3}$). However, if the suggested odour impact criterion ($C_{98,1-h} \leq 9.7 \text{ ou}_E \text{ m}^{-3}$) is implemented, the maximum setback distances decrease to 460, 500 and 785m for broilers, layers and turkeys, respectively. The meteorological data used in an odour impact assessment should be as representative as possible to the local climatic conditions surrounding the site.

Keywords: Poultry, atmospheric dispersion modelling, odour, setback distance, meteorological data.

1. Introduction

The intensification of agricultural enterprises and the urban encroachment on agricultural areas has led to an increase in odour complaints to local authorities. Odour sensation might cause annoyance depending on the individual and the sociological situation of the person (Piringer and Schaubberger, 1999). Numerous steps can be taken to ensure that neighbouring odour sensitive receptors do not have cause to complain. These include the implementation of abatement techniques for existing units or the determination of accurate setback distances and appropriate siting of new units.

It has become standard practice to use atmospheric dispersion models to predict the occurrence of odour nuisances around intensive animal facilities (Curran et al., 2002). Another method is to use trained “sniff squads” to assess the odour impact of the production unit. This method has become popular in some parts of the US and Europe but is thought to be time consuming, expensive and largely dependant on local meteorological conditions.

The choice of atmospheric dispersion model to use can be problematic due to the lack of peer-reviewed data on model validation regarding odour (Curran et al., 2002). There are numerous commercial models available around the world (e.g. ISC, AERMOD, ADMS3). The difference between the models can be critical in borderline cases especially if the results are used to determine setback distances and abatement

techniques as part of a regulatory framework (Sheridan et al., 2004). The Gaussian equation mathematically describes the dispersion process that produces a plume of polluted air (Carney and Dodd, 1989; Smith, 1995). Originally a Gaussian form model ISC (Industrial Source Complex) (Keddie, 1980) was used but more recently the models have utilised more advanced boundary layer physics (ADMS, AERMOD) (Hall et al., 1999).

Atmospheric dispersion modelling can be used in three ways for poultry units:

1. To determine the odour impacts that existing or proposed units will have on the surrounding area.
2. To calculate approximate setback distances for new units and to site the units appropriately.
3. To estimate the maximum odour emission permitted and which abatement techniques will prevent odour complaints occurring.

This paper illustrates a dispersion modelling approach to determine the odour impact of intensive poultry production units. Odour impact criteria, input parameters and model selection for a broiler, layer and turkey production units were assessed.

2. Materials and Methods

2.1. Odour annoyance criteria

Five factors (FIDOR factors) have been identified in relation to odour impact (Sheridan, 2002). These are:

- Frequency (number of times an odour is detected over a specific time period)
- Intensity (the strength of the odour)
- Duration (length of exposure)
- Offensiveness (hedonic tone)
- Receptor (physiological aspects of the individual perceiving the odour)

The development of an odour impact criterion is time consuming and complex (Sheridan et al., 2004). Many different techniques for developing such criterion exist including questionnaires and telephone surveys. VDI guideline 3883 (1993) describes a methodology for the estimation of a person's response. Different odour impact criteria have been used in various countries depending on the odour generating industry. In Ireland, 1 hour odour concentrations of $6 \text{ ou}_E \text{ m}^{-3}$ (for existing facilities) at the 98th percentile is implemented for intensive agricultural facilities, mushroom compost facilities and the tanning industry in order to limit complaints (EPA, 2001). This criterion was originally established for pig production facilities but has been adopted to facilitate poultry production units. It was based on results of a large scale study into the relationship between exposure to pig odours and annoyance in the exposed populations (EPA, 2001). It has been specifically interpreted to arrive at a framework of environmental quality criteria for Ireland, which would reduce the percentage of the population 'annoyed' by odour exposure to less than 10% of the resident population in the vicinity of existing intensive agricultural production

systems. A similar criterion has been utilised in the Netherlands for intensive pig units and is acceptable to regulatory agencies and the public (EPA, 2001). In comparison to other forms of air pollution, odours will cause an effect almost instantly in receptors due to the nature of the human olfactory system. However, the 1-hour mean concentration period was used as dispersion models are not typically designed nor validated to be used at smaller averaging periods (EPA, 2001).

2.2. Development of a dose effect relationship using odour intensity measurement

The determination of an odour threshold alone is not an adequate criterion for assessing an odorant (VDI, 1993). Odour intensity is a subjective measurement of the strength and unpleasantness of an odour (Misselbrook et al., 1993). The odour intensity for poultry odour was carried out according to VDI 3882 guidelines (1992). Thirty-two air samples were collected over a 12 month period from broiler, layer and turkey units in Ireland (Hayes et al., 2005). After the odour concentration was established using the EN13725 European standard the air sample was presented to eight pre-screened panellists using an ECOMA T07 olfactometer. When the first four panellists finished the sequence the second group of four began. The panel members were presented a sample of odorous gas from which they had one minute to classify their odour impression in accordance with the concepts specified in the following scale: not perceptible (0); < very weak (1); < weak (2); < distinct (3); < strong (4); < very strong (5); < extremely strong (6). The sequence of the presented concentration levels was selected at random. The mean intensity scores from each panellist were obtained at each dilution and the concentration of the odour at each dilution was calculated as the sample concentration divided by the dilution factor (Misselbrook et al., 1993).

2.3. Model selection

There are numerous commercial atmospheric dispersion models available (ISC, AERMOD, ADMS etc.). ISCST3 atmospheric dispersion modelling software (Trinity Consultants, Dallas) was used to determine the odour impact from theoretical broiler, layer and turkey units. This model was chosen due to the validation studies that have been carried out on the dispersion of odours (Sheridan, 2002). ISCST3 is a straight line trajectory, Gaussian based model based on the 1960's description of boundary-layer physics.

2.4. Input data

The model input data includes source characteristics, meteorological data, topography of the area and odour emission rates. Topographical data can be used in the models as it can have a significant effect on the odour plume dispersion and the predicted odour concentration at a specific odour sensitive receptor (Casey, 2002). Topographical data was not used in these models as it was assumed that the surrounding terrain was uniformly flat.

2.4.1. Source characteristics

Seven scenarios were modelled: broilers, layers and turkeys at the Integrated Pollution Control (IPC) and the Integrated Pollution Prevention and Control (IPPC) limits of birds, and a turkey unit, representative of an average Irish unit, accommodating 10,000 birds. The source characteristics include the building dimensions (length, width, height and angle), source type and dimensions (point, line, area, volume or flare), efflux velocity, temperature and odour emission rates. The hypothetical poultry production units consisted of uniform rectangular buildings with continuous ridge

ceiling vents for the broiler and turkey units and 0.6 m roof fans for the layer units. This is generally representative of the typical ventilation designs found in Irish poultry production units.

2.4.2. Meteorological data

Meteorological data was run in an hourly sequential format using the following information: wind speed, wind direction, mixing heights, temperature and Pasquill-Gifford stability classes (Figures 1a, 1b and 1c illustrates the windrose for Casement, Claremorris and Cork meteorological stations respectively). In this study meteorological data from Casement (1993-1995), Cork (1993-1995) and Claremorris (1993-1995) was used as these stations were representative of typical climatological conditions in the east, south and west of Ireland. They also were the three stations with the most up to date and complete meteorological data sets. Casement meteorological station is located in the east of Ireland and 94 m above sea level. Due to its location close to a range of mountains to the east it is subject to strong winds from a southwesterly direction. Cork meteorological station is located close to the southern coastline of Ireland and is 104 m above sea level. Claremorris meteorological station is the most inland of the three stations utilised and is 71 m above sea level. From a climatological standpoint it is possibly the most ideal of the three stations due to its unobstructed view in all directions. The meteorological data used in an odour impact assessment should be as representative as possible to the local climatic conditions surrounding the unit.

2.4.3. Odour emission rates for poultry production unit

The odour emission rates used in the dispersion models in this paper are taken from research reported by Hayes et al. (2005). The odour emission rates were measured using the EN13725 European standard for dynamic olfactometry (CEN, 2003). Due to the lack of unanimity in the literature and a scarcity of published data, particularly for turkey odour, and as a precautionary principle until a full odour emission rate data set is available, it is recommended that the worst-case scenario should be modelled.

Therefore, the maximum odour emission rates reported for the broiler ($1.22 \text{ ou}_E \text{ s}^{-1} \text{ bird}^{-1}$) and turkey ($10.5 \text{ ou}_E \text{ s}^{-1} \text{ bird}^{-1}$) production units and the mean odour emission rate for the layers ($1.35 \text{ ou}_E \text{ s}^{-1} \text{ bird}^{-1}$) unit were used (Table 1). The maximum emission rate was utilised for broilers and turkeys due to the nature of the animal production cycle. Hayes et al. (2005) reported the maximum emission rate occurred when the birds reached slaughter weight and the manure within the house was at its highest level (i.e. just before the birds are removed and the house cleaned). The mean emission rate was used for layer units as the birds within the unit remain at a relatively constant weight and manure is usually removed frequently during the production period thus minimizing fluctuations in odour emissions.

3. Results and Discussion

3.1. Odour annoyance criteria

Linear regression was used to calculate the odour intensity relationship from 32 odour intensity measurements from broilers, layers and turkeys (Figure 2). A relationship (Equation 1) can be illustrated when the odour intensity (I) is plotted against \log_{10} of the odour concentration:

$$\text{Equation 1: } I = 2.21(\log_{10} [\text{odour concentration}]) + 0.82$$

Using this equation, the distinct odour concentration ($I = 3$), which could be perceived as an odour nuisance (Jiang, 2000), can be determined. The distinct odour concentration calculated in this study for poultry production units was $9.7 \text{ ou}_E \text{ m}^{-3}$. This value falls within the range of $8.8 - 23.4 \text{ ou}_E \text{ m}^{-3}$ reported for broiler housing by Misselbrook et al. (1993) and is similar to the odour impact limit of $5 \text{ ou}_E \text{ m}^{-3}$ (1-hr, 99.5%-ile) for broiler production in Australia (Jiang and Sands, 2000). This relationship could be useful in estimating the reduction in odour concentration necessary to reduce the perceived intensity of the odour to acceptable levels (Misselbrook et al., 1993). The current odour impact criterion recommended by the Irish EPA ($C_{98,1-h} \leq 6.0 \text{ ou}_E \text{ m}^{-3}$) for existing units would appear to be conservative in relation to the suggested criterion of $C_{98,1-h} \leq 9.7 \text{ ou}_E \text{ m}^{-3}$ established in this study. Further research is ongoing at University College Dublin on the validation of results from atmospheric dispersion models and will be reported later.

3.2. Odour emission rates

Table 1 contains the odour emission rates and bird numbers used in the modelling scenarios. The IPC and IPPC limits on bird numbers were utilised in this study.

Turkey production systems in Ireland utilise satellite units around a central hub unit. An average large turkey satellite unit in Ireland would house approximately 10,000 birds; therefore this size of farm was also modelled to determine the setback distances required. The turkey units have the highest total emission rate due to the high odour emission rates per bird.

3.3. Influence of meteorological data

The impact distances that the units can have on the surrounding area are illustrated in Table 3. The minimum and maximum setback distances for the three meteorological stations are reported at the 98%-ile, 1-h average at the EPA $6 \text{ ou}_E \text{ m}^{-3}$ limit and the $9.7 \text{ ou}_E \text{ m}^{-3}$ limit isopleths. As illustrated in Figure 2, the lower the odour annoyance criteria the greater the impact. Figure 2 also shows how the maximum and minimum distances were determined.

The IPC and IPPC limits for broilers are typical of the size of unit found in Ireland and in both cases the Casement data had the largest impact area of over 1150m and 660m respectively at the $6.0 \text{ ou}_E \text{ m}^{-3}$ limit. It should be noted that in the case of the IPC limit the Cork data could be regarded as having a more significant impact than the Casement data as the maximum distances were similar (1030 m and 1150 m for the $6 \text{ ou}_E \text{ m}^{-3}$ limit respectively) but the minimum distance for the Cork data was much larger (Casement min 80 m, Cork min 200 m). Statistical analysis of the results

obtained from the dispersion modelling exercise using the three different meteorological data sets found that both Casement and Cork results were significantly different to Claremorris results ($p \leq 0.001$). This may be due to the higher wind speeds at Claremorris compared to Cork and Casement (Figures 1a, 1b and 1c).

The layers had slightly smaller setback distances than the broilers for the IPC and the IPPC limits of birds. This is due to the lower total odour emission rates for the IPC limits and the differences in the ventilation systems of each house type. The majority of laying houses in Ireland utilise automatically controlled mechanical ventilation which would have better odour dispersion qualities than the automatically controlled natural ventilation (ACNV) predominantly used in broiler housing (Hayes et al., 2005). ACNV is a form of natural ventilation by which the airflow through the building is regulated by adjusting the inlet and outlet vents to maintain a preset internal temperature.

The turkey units using the IPC and IPPC limits of birds had maximum distances of over 3000m. The Irish unit of approximately 10,000 birds had a maximum setback distance of over 1000m for the $6 \text{ ou}_E \text{ m}^{-3}$ limit. The implementation of odour abatement techniques has been well documented for the reduction of malodours from intensive pig production units but their applications to poultry production are limited. Good management practices, improved ventilation and manure management systems can reduce odour emission and improve dispersion from the poultry house, thus reducing the potential impact on the surrounding area. The potential for minimising the generation of odours using dietary manipulation has been well documented for intensive pig production (Hayes et al., 2005; Peirson and Nicholson, 1995). Research

into the applications of a similar minimisation technique for the reduction of emissions from poultry production has been identified as the most promising prospect for the future (Phillips et al., 1998; Gates, 2000; Robertson et al., 2002).

Integrated Pollution Control Licensing (IPC) for pig and poultry production was introduced in Ireland in 1996 and the related guidance note was termed BATNEEC (Best Available Technology Not Entailing Excessive Cost) (EPA, 1996); this guidance note recommends a 400 m setback distance in all directions from all sites. The output from atmospheric dispersion models indicates that units can be located nearer (or further) than the recommended 400 m depending on the location of the site and any neighbouring sensitive receptors. The current IPPC limits for poultry units may not be representative of the average size units in some European countries as many turkey units would not have the capacity to accommodate 40,000 birds. Overall broiler and layer units at the IPC and IPPC limit of birds and a turkey unit with 10,000 birds would require setback distances similar to those required for a 1000 sow integrated pig production unit (Sheridan et al., 2004) and are within the recommended range of setback distances in many regulatory guidelines for intensive agricultural enterprises.

3.4. Comparison of odour impact criteria

Odour impact criteria are not ambient odour standards but rather provide a scientifically derived benchmark for the making of informed decisions in planning, design, environmental management and regulation (Jiang and Sands, 2000). Various odour impact criteria have been reported for poultry units around the world (Table 3). The comparison of odour impact criteria and setback distances utilised in different

countries is difficult due to the variation in topography, climate and management practices. Care should also be taken regarding choosing an odour impact criterion as advances in dynamic olfactometry and the introduction of odour measurement standards could result in many of the limits quoted in Table 3 being incompatible with current practice. This would also help to explain, to some extent, the substantial variation in the limits reported.

4. Conclusions

The conclusions from this study for the dispersion of odours from poultry production units are:

- Setback distances for broilers, layers and turkey units were determined using the atmospheric dispersion modelling software ISCST3 and the Environmental Protection Agency (EPA, Ireland) recommended criterion ($C_{98,1-h} \leq 6 \text{ ou}_E \text{ m}^{-3}$) and a new odour annoyance criterion ($C_{98,1-h} \leq 9.7 \text{ ou}_E \text{ m}^{-3}$) developed in this study.
- Using the average size unit in Ireland; maximum setback distances of 660, 665 and 1035m were calculated for broilers (40,000), layers (40,000) and turkeys (10,000) respectively at the current limit ($C_{98,1-h} \leq 6 \text{ ou}_E \text{ m}^{-3}$). However, if the suggested odour impact criterion ($C_{98,1-h} \leq 9.7 \text{ ou}_E \text{ m}^{-3}$) is implemented, the maximum setback distances decrease to 460, 500 and 785m for broilers, layers and turkeys respectively.
- The meteorological data used in an odour impact assessment should be as representative as possible to the local climatic conditions surrounding the site.

5. Acknowledgements

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Table 3. Comparison of published odour impact criteria for poultry

Table 1. Odour emission rates for intensive poultry production units

Process description	Number of birds	Emission rate per bird (ou _E s ⁻¹ bird ⁻¹)	Emission rate per process (ou _E s ⁻¹)
IPC Limit ¹			
Broilers	100,000	1.22	122,000
Layers	50,000	1.35	67,500
Turkeys	50,000	10.5	525,000
IPPC Limit ²			
Broilers	40,000	1.22	48,800
Layers	40,000	1.35	54,000
Turkeys	40,000	10.5	420,000
Irish Units ³			
Turkeys	10,000	10.5	105,000

¹ IPC limit is 100,000 units where 1 broiler = 1 unit and 1 layer or turkey = 2 units

² IPPC limit is 40,000 units where 1 broiler, layer or turkey = 1 unit

³ 10,000 bird unit represents the average size of a large turkey production unit in Ireland at present.

Table 2. Odour impact distances for poultry production units using data from three meteorological stations for 98%-ile, 1-hr average at the $\leq 6.0 \text{ ou}_E \text{ m}^{-3}$ and the $\leq 9.7 \text{ ou}_E \text{ m}^{-3}$ isopleths

Process	Limit	Casement		Cork		Claremorris	
Description	98%-ile, 1-hr	Min	Max	Min	Max	Min	Max
IPC Limit							
Broilers	$6.0 \text{ ou}_E \text{ m}^{-3}$	80	1150	200	1030	190	595
	$9.7 \text{ ou}_E \text{ m}^{-3}$	55	860	165	780	160	445
Layers	$6.0 \text{ ou}_E \text{ m}^{-3}$	50	775	145	690	150	585
	$9.7 \text{ ou}_E \text{ m}^{-3}$	25	585	110	525	150	440
Turkeys	$6.0 \text{ ou}_E \text{ m}^{-3}$	200	3000+	450	3000+	450	1575
	$9.7 \text{ ou}_E \text{ m}^{-3}$	180	2245	365	2045	400	1210
IPPC Limit							
Broilers	$6.0 \text{ ou}_E \text{ m}^{-3}$	SB ¹	660	80	570	125	330
	$9.7 \text{ ou}_E \text{ m}^{-3}$	SB	460	35	425	75	250
Layers	$6.0 \text{ ou}_E \text{ m}^{-3}$	SB	665	100	600	135	355
	$9.7 \text{ ou}_E \text{ m}^{-3}$	SB	500	60	455	90	265
Turkeys	$6.0 \text{ ou}_E \text{ m}^{-3}$	190	3000+	420	2300	430	1240
	$9.7 \text{ ou}_E \text{ m}^{-3}$	170	2040	355	1695	365	920
Irish Units							
Turkeys	$6.0 \text{ ou}_E \text{ m}^{-3}$	60	1035	200	880	195	515
	$9.7 \text{ ou}_E \text{ m}^{-3}$	55	785	165	690	155	385

¹ Any distance marked SB signifies that the odour contour line fell within the poultry unit site boundary.

All distances are estimated to the closest 5m.

Table 3. Comparison of published odour impact criteria for poultry

Country	Odour concentration (ou m ⁻³)	Percentile (%)	Averaging time	Receptor
This Study	9.7	98	1 hour	Closest sensitive receptor
Ireland ¹	6 (existing unit)	98	1 hour	Closest sensitive receptor
	3 (new units)	98	1 hour	Closest sensitive receptor
	1.5 (recommended)	98	1 hour	Closest sensitive receptor
Denmark ²	5-10	99	1 min	Plant surroundings
	0.6-20	99	1 hour	Plant surroundings
Australia ³	2 (NSW)	99.5	3 min	Resident
	10 (Queensland)	99.5	1 hour	Resident
	1 (Victoria)	99.9	3 min	Resident
The Netherlands ⁴	1 (new units)	99.5	1 hour	Domestic dwelling
United Kingdom ⁵	3 (new units)	98	1 hour	Specified receptor
New Zealand ⁶	2	99.5	1 hour	Property boundary
USA ⁷	5	Highest	1 hour	Plant boundary

1: EPA, 2001; 2, 3, 4, 6 and 7: Jiang and Sands, 2000; 5: Environment Agency, 2003

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Figure 1a. Meteorological windrose for Casement

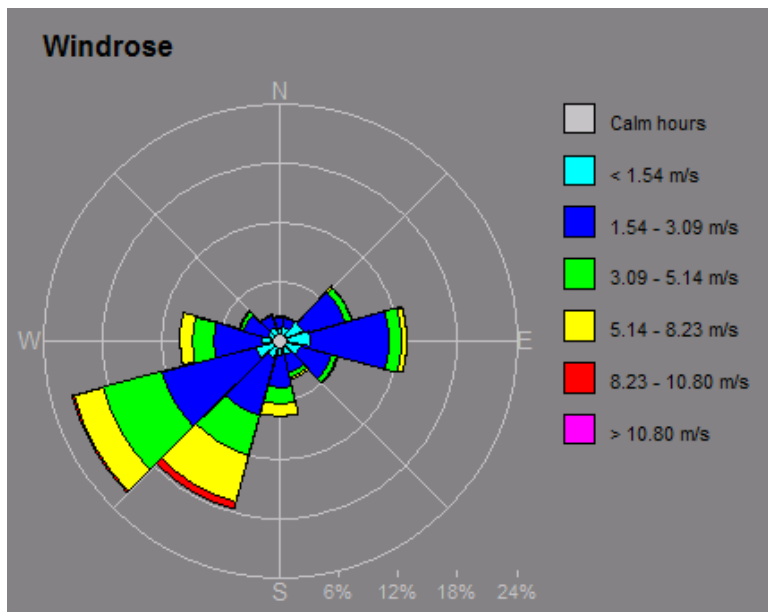


Figure 1b. Meteorological windrose for Claremorris

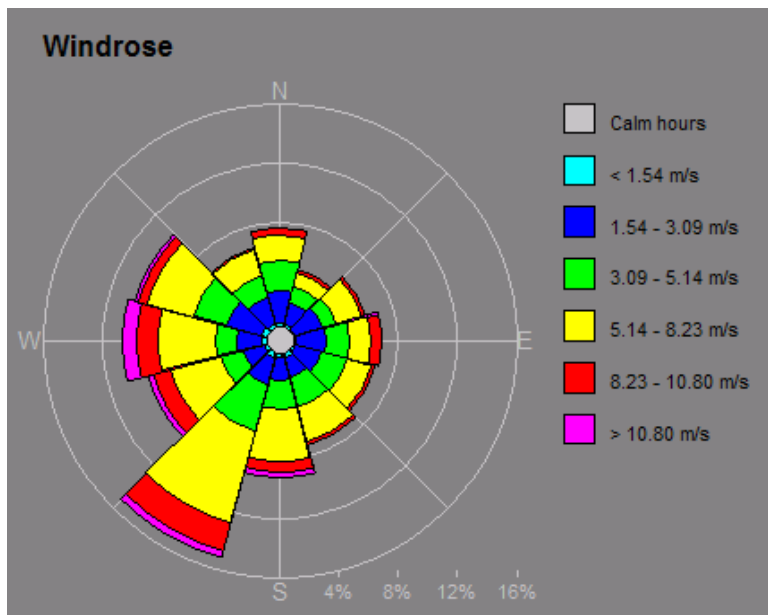


Figure 1c. Meteorological windrose for Cork

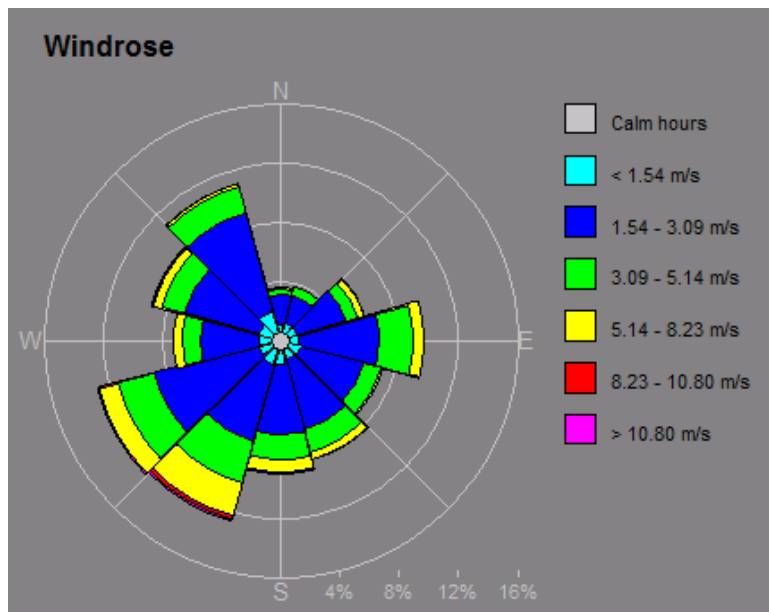


Figure 2. Odour intensity relationship for poultry odour

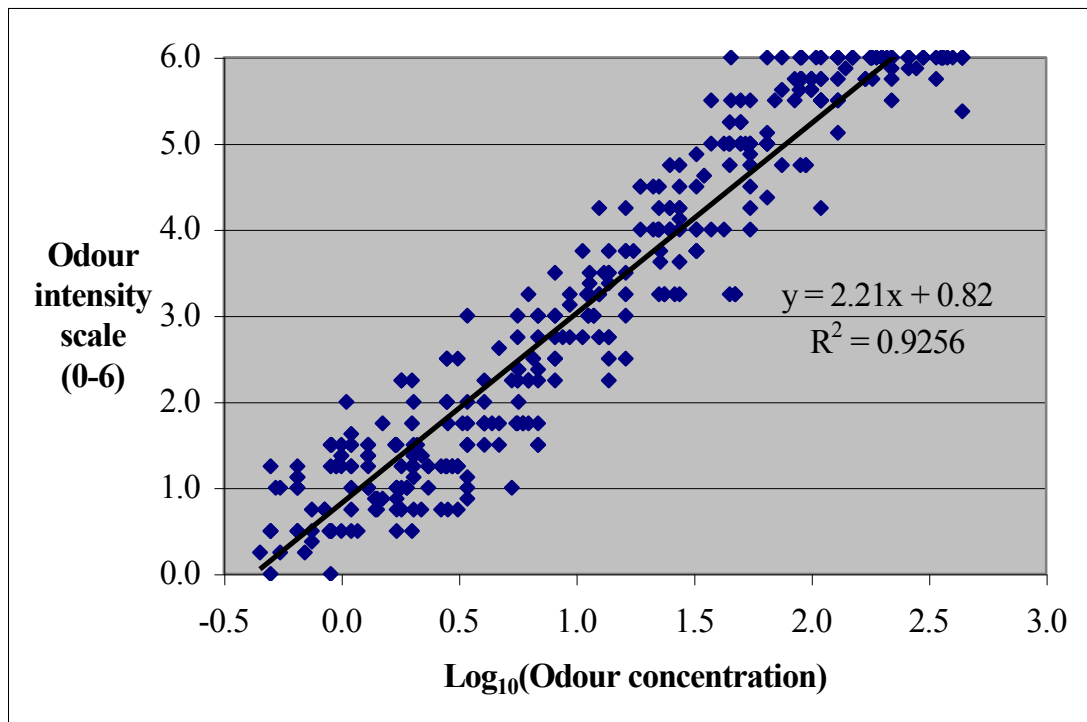


Figure 3. An example contour map illustrating the minimum and maximum setback distances from a 10,000 bird turkey production unit based on the limit $C_{98,1-h} \leq 6.0 \text{ ou}_E \text{ m}^{-3}$ (red line) and the limit $C_{98,1-h} \leq 9.7 \text{ ou}_E \text{ m}^{-3}$ (blue line) using Casement meteorological data.

