Comparison of five models for setback distance determination from livestock sites

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Guo, H., Jacobson, L.D., Schmidt, D.R., Nicolai, R.E. and Janni, K. 2004. **Comparison of five models for setback distance determination from livestock sites.** Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **46**: 6.17-6.25.
Different setback estimation models for animal production farms have been developed in European countries and some states and provinces in North America. Five setback models, based on empirical, combination of empirical and odour measurement, or odour dispersion calculation, were compared for various sizes of swine farms. The setback distances generated by different models were found to fall into a wide range. The Minnesota OFFSET model gave the occurrence frequency of faint odour at various distances away from an odour source and produced different setback distances according to odour annoyance free frequencies from 91% up to 99%. The Ontario MDS-II model and the Austrian model generated low setback distances that were close to OFFSET's setbacks at the 91 and 94% levels, however, the Austrian model did not consider outdoor manure storage units. The Purdue model produced medium setback distances similar to 94 to 97% annoyance free level of the Minnesota OFFSET model. Finally, the Williams and Thompson model (W-T model), from the Warren Spring Laboratory in England, gave setbacks similar to OFFSET 98% odour annoyance free distance. The relative results from the models and the methods used by them to calculate setback distance should be helpful to local government officials or designers when choosing a model to use for land use guidelines or specific case studies. **Keywords:** odour, setback distances, air dispersion model, livestock.

Différents modèles d'estimation de distances séparatrices pour des fermes de production animale ont été développés en Europe et dans certains états et provinces de l'Amérique du Nord. Cinq modèles de distances séparatrices, basés sur des données empiriques, des combinaisons de données empiriques et mesures d'odeur ou des calculs de dispersion d'odeur, ont été comparés dans le cas de fermes porcines de différentes tailles. Les distances séparatrices obtenues à l'aide de ces différents modèles ont montré une grande variation. Le modèle Minnesota OFFSET a donné la fréquence sans nuisance olfactive à différentes distances d'une source d'odeur et a fourni des distances séparatrices selon des fréquences sans nuisance olfactive de 91% à 99%. Le modèle MDS-II de l'Ontario et le modèle autrichien ont généré de faibles distances séparatrices qui étaient près des distances séparatrices du OFFSET aux niveaux 91 et 94%, toutefois le modèle autrichien n'a pas considéré les structures extérieures d'entreposage du fumier/lisier. Le modèle de Purdue a produit des distances séparatrices moyennes similaires aux niveaux 94 to 97% sans nuisance olfactive du modèle OFFSET du Minnesota. Finalement, le modèle Williams et Thompson (modèle W-T), du laboratoire Warren Spring en Angleterre, a donné des distances séparatrices similaires aux distances de OFFSET pour 98% sans nuisance olfactive. Les résultats respectifs des modèles et méthodes utilisés pour calculer les distances séparatrices devraient s'avérer utiles pour les concepteurs ainsi que pour les responsables gouvernementaux lors de la sélection d'un modèle pour l'élaboration de directives d'utilisation du territoire ou pour l'étude de cas particuliers. **Mots clés**: odeur, distances séparatrices, modèle de dispersion, élevage

INTRODUCTION

The odour nuisance complaints against animal production farms have been increasing rapidly in the last several years and are becoming one of the main barriers for the expansion and development of the livestock industry. Determining appropriate setback distances between neighboring residents and farms has become an urgent need for the livestock industry and regulating agencies. Large setback distances tend to restrict the development and expansion of the animal industry, whereas insufficient separation distances result in odour complaints or even law suits against the animal producers.

Odour emissions from animal production facilities are a function of many variables including: species, housing types, feeding methods, manure storage and handling methods, the size of the odour sources, and weather conditions. The impact of these odours on the surrounding neighbors and communities depends on the amount of odour emitted from the site, the distance from the site, weather conditions, topography, and odour sensitivity and tolerance of the neighbors. Each of these factors is highly variable, which makes it difficult to determine a proper setback distance.

Most of the existing setback distances are determined either by individual judgement and experience or by a combination of neighbor surveys and odour measurement, instead of calculations by dispersion models. Some European countries (Austria, Germany, Switzerland, Netherlands, etc.), and some states or provinces in North America (Ontario, Illinois, Purdue, Iowa, etc.) have developed setback guidelines during the last two decades (CIGR 1994; VDI 3471 1986; VDI 3472 1986; VDI 3473 1994; Klarenbeek and Harreveld 1995; Lim et al. 2000). Among these guidelines, the Austrian guideline is one of the typical models that considered the most factors (Schauberger and Piringer 1997). It is an empirical model based on an estimation of odour sources by the following parameters: animal number, animal species, housing systems, ventilation systems, handling of manure inside the building, the feeding methods, land use, and topography. This model was compared with the Switzerland, Germany, and Netherlands models (Schauberger and Piringer 1997). This model was found to be different from the others in that it a) uses the worst-case assumption, b) has a common treatment of different animals and building systems, c) includes the meteorological and topographic effects, d) uses a power function with exponent of 0.25 to determine the interrelation between the source strength and the protection distance, whereas Germany and Swiss models use 0.33 for the exponent, and e) considers the effect of land use.

In Ontario, Canada, the *Minimum Distance Separation* guidelines (*MDS-I and II*) (OMAFRA 1995a) along with the *Guide to Agricultural Land Use* (OMAFRA 1995b) were developed by the Ontario Ministry of Agriculture, Food, and Rural Affairs in the 1990's and are the successors to the 1976 *Agricultural Code of Practice* (OMAF 1976). MDS-I is for siting new residences from existing livestock operations while MDS-II is for siting new livestock operations from existing residences. The models determine the setback distance according to the animal species, animal numbers, and manure handling systems. These guidelines were generated with the help of some science-based information and a lot of personal experience with determining setbacks from livestock operations in the province (OMAFR 1995a; MacMillan and Fraser 2003). They have been used for approximately 30 years in Ontario and have been incorporated in land use policy throughout the province.

In the United States, a model developed by Purdue University (Lim et al. 2000) is an empirical model based on the baseline odour emission data, literature review, and study of existing setback guidelines, particularly the Austrian model (Schauberger and Piringer 1997) and Williams and Thompson model (Williams and Thompson 1986). Building design and management and odour abatement factors were introduced to replace the technical factor of the Austrian model. Outdoor manure storage sources were also incorporated.

A concern with these and similar models is that they are made with the assumption that a site with greater animal numbers generates more odours, and therefore requires larger separation distances. This would be true if all operations were identical. However, with the diversity of manure handling systems, facility designs, and the new odour control technologies currently being developed, farm size is not the only variable in odour emissions (LOTF 1997). For instance, European farms either have no outdoor manure storage or have good odour control measures for the outdoor storage facilities, while in North America the outdoor storage units are usually uncovered. Hence, the total odour emissions from different farms with the same animal species and number can be quite different. Therefore, separation distance should be based on the actual odour emission instead of animal numbers.

Odour dispersion models have great potential for simulating odour concentrations downwind of animal production sites and further determining reasonable setbacks. Since the early 1980s, air dispersion models have been studied to predict odour concentrations downwind from agriculture sources (Guo et al. 2002). However, very few models have been used for setback distance determination because of limited field data available to validate the models. In the last several years, extensive odour source measurements were conducted from livestock and poultry farms in Minnesota (Schmidt et al. 2000; Li et al. 1994). Also, downwind odour plume measurements in the field by trained sniffers have been done (Li et al. 1994; Hartung and Jungbluth 1997; Zhu et al. 2000; Guo et al. 2002).

In Minnesota, the Odour From Feedlots Setback Estimation Tool (OFFSET model) has been developed to estimate the setback distance from animal production sites (Jacobson et al. 1999; 2000). It is based on extensive odour emission measurements, an air dispersion model, and historical weather data of Minnesota. The setback distances can be chosen according to the total odour emission rate and the desired odour annoyance free frequency of the neighbors.

Williams and Thompson (1986), from the Warren Spring Laboratory in England, measured odour emissions from a number of processes and sources. By collating the emissions with data on the spatial extent of odour complaints, an empirical formula, i.e. W-T model, was derived relating the maximum setback distance from the source. They also used dispersion models to calculate the odour concentrations downwind from the source and found the dispersion modeling approach provided reasonably accurate results as compared with the empirical formula.

Different setback models have been developed based on different methods. The objective of the current study was to compare the setback distances generated by five existing models, Ontario's MDS-II model, Austrian model, Purdue model, W-T model, and Minnesota's OFFSET model, when used on 13 existing swine farms. These models were selected because they were considered to be representative of setback models generated by various methods.

MATERIALS and METHODS

Descriptions of the models

Ontario MDS-II model Ontario MDS-II has separate procedures for buildings and manure storage units. The building separation base distance is defined as the product of four factors:

$$F(m) = Factor\ A \times Factor\ B \times Factor\ C \times Factor\ D \quad (1)$$

where:

Factor A = tabulated value as function of type of animal (range of values from 0.65 for broiler chickens to 1.1 for adult mink, 1.0 for swine barns).

Factor B = tabulated value as function of number of livestock units (LU) (range from 107 for 5 LU to 1,455 for 10,000 LU). For swine, five sows or boars, 20 nursery pigs, or 4 feeder hogs make up 1 LU.

Factor C = tabulated value as function of percentage increase in animal numbers (range from 0.7 for 0 to 50% increase to 1.14 for 700% increase or new facility).

Factor D = tabulated value as function of type of manure system (solid = 0.7 and liquid = 0.8).

This base separation distance is adjusted by a neighboring land use factor, Factor E. Factor E is 1 for nearest residence and areas zoned for agriculturally related commercial use, or 2 for areas zoned for residential, commercial, or urban areas. The final required distance from the barns is:

$$Distance(m) = F \times Factor\ E \quad (2)$$

The manure storage separation distance is a tabulated value that is a function of the base building distance F and the type of manure storage system (covered, open solid and runoff, open liquid tank and runoff, and earthen liquid and runoff). Manure storage separation distances in MSD-II vary from a minimum of 40 m to a maximum of 550 m. After this distance is obtained, Factor E is then used to adjust this base distance to required setback distance from the manure storages according to the neighboring land use.

W-T Model The W-T model was obtained by collating odour emissions with data on the spatial extent of odour complaints. The derived empirical formula (Eq. 3) relating the maximum setback distance (D_{max}, meters) from the source within which complaints were likely due to the odour emission E (OU/s) is (Williams and Thompson 1986):

$$D_{\max} = \left(2.2E\right)^{0.6} \tag{3}$$

The estimated range of uncertainty in the maximum setback distance was $(0.7\ E)^{0.6}$ to $(7\ E)^{0.6}$.

Austrian Model For the Austrian model, the odour number estimates the odour emission. The odour number is calculated by considering number and type of animals, the housing system, the geometry of the outlet air, the vertical velocity of the outlet air, the handling of manure inside the livestock building, and the feeding system (Schauberger and Piringer 1997). Outdoor manure storage facilities were not considered in this model.

The odour number O is first quantified for all odour building sources on the site by:

$$O = Zf_A f_T \tag{4}$$

where:

- O = odour number describing the amount of odour emitted from the site (dimensionless),
- Z = number of animals,
- f_A = animal factor, depends on animal species and housing type (0.10 to 0.33, taken as 0.33 in this study), and
- f_T = technical factor, a measure of the technical equipment of the livestock building, such as ventilation, manure treatment, and feeding.

The technical factor is calculated by:

$$f_T = f_V + f_M + f_F \tag{5}$$

where:

- f_V = ventilation factor (0.10 to 0.50, taken as 0.50 in this study),
- f_M = manure treatment factor inside the building (0.10 to 0.30 for poultry and 0.27 for other animals) and
- f_F = feeding factor (0.05 to 0.20, 0.1 for dry feed).

The separation distance is calculated by:

$$D_{\min} = 25 f_D f_L O^{0.5} \tag{6}$$

where:

- D_{min} = minimum protection distance (m),
- f_D = dispersion factor considering wind distribution and topography (0.6 to 1.0 in a flat and windy area, 0.6 and 0.7 without and with obstacles in the vicinity of the barns, respectively), and
- f_L = land use factor (0.5 for agricultural areas to 1.0 for recreation and residential areas).

Purdue model This model was based on the features of the Austrian and W-T models and incorporates several new features including building design and management, odour abatement factors, and outdoor manure storages (Lim et al. 2000). Setback is estimated from:

$$D = 6.19 FLTV\left(A_E E + A_S S\right)^{0.5} \tag{7}$$

where:

- D = setback distance (m),
- F = wind frequency factor (0.75 to 1.00, taken as 1.00 in this study),
- L = land use factor (0.5 to 1.0),
- T = topography factor (0.80 to 1.00, considered as 0.8 for flat area without obstacles in this study),
- V = orientation and shape factor (1.00 to 1.15),
- E = building odour emission, E = N P B (OU/s),
- N = number of pigs,
- P = odour emission factor (OU/s-pig),
- B = building design and management factor, B = M-D,
- M = manure removal frequency (0.50 to 1.00, taken as 1.00 in this study),
- D = manure dilution factor (0.00 to 0.20, taken as 0.00 in this study),
- S = odour emission from outdoor storage, $S = C \cdot G$ (OU/s),
- C = odour emission factor for outside liquid manure storage (50 OU/s-AU),
- G = animal units (1 AU = 500 kg of pig mass),
- A_E = odour abatement factor for buildings (0.30 to 1.00 with no odour abatement measure), and
- A_S = odour abatement factor for outside liquid manure storage (0.30 to 1.00 with no odour abatement measure).

Minnesota OFFSET model The OFFSET model was developed based on numerous odour emission measurements, an air dispersion model (INPUFF2) developed by the United States Environmental Protection Agency, and historical weather data of Minnesota (Jacobson et al. 2000). This model calculates the odour concentration downwind from the source by the air dispersion model. The setback distances are determined by the total odour emission rate and the desired odour "annoyance free" frequency (91 to 99%). Odour emissions are estimated by source type and dimensions. The odour emission numbers for different animal housing systems and various manure storage units in Minnesota are the geometric means of the odour emission rates measured from more than 260 animal buildings and manure storage units on over 80 farms across Minnesota from 1997 to 2001. Table 1 gives the odour emission numbers for swine production facilities (Wood et al. 2001; Jacobson et al. 2000). Various odour control technologies are also given credit. The total odour emission factor is calculated by:

$$E = \sum_{i=1}^{n} E_i = \sum_{i=1}^{n} E_{ei} \times A_i \times f_{ci} \tag{8}$$

where:

- E = total odour emission factor from an animal production site (dimensionless),

Table 1. Odour emission numbers for swine production facilities with an average management level in Minnesota (Wood et al. 2001; Jacobson et al. 2000).

Swine type	Housing/storage type	Odour emission number
Gestation barn	Deep pit	538
	Pull plug	323
Farrowing barn	Deep pit	323
	Pull plug	151
Nursery barn	Deep pit	452
	Pull plug	
Finishingbarn	Deep pit	366
	Pull plug	215
Earthen manure storage basin	Single or multiple cells with no crust	140

E_i = odour emission from source i, i = 1 to n, where n is total number of odour sources (dimensionless),
E_{ei} = odour emission number of source i on per square meter basis (ranges from 11 to 538 for various buildings and manure storage facilities),
A_i = area of source i (m^2), and
f_{ci} = odour control factor of source i, ratio of odour emission rate of an odour source using an odour control technology and without that odour control measure (varies from 0.1 to 0.6 for different odour control technologies such as biofilter, various basin covers, and oil sprinkling; if no odour control technology incorporated, f_{ci} = 1.

The total odour emission, E, and six typical weather conditions are inputted into the dispersion model that determines setback distances for different odour annoyance free frequency levels. The separation distance and the total odour emission are highly correlated on a power relationship as:

$$D = aE^b \tag{9}$$

where:
D = separation distance (m), and
a,b = weather influence factors for various odour frequency requirements. Values are given in Table 2.

Odour intensity level for annoyance free is set at an intensity of 2 (faint odour) on a 0 (no odour) to 5 (very strong odour) intensity scale (ASTM 1999). Odour annoyance free frequencies for Minnesota are based on the average weather data of six weather stations in Minnesota from 1984 to 1992. The odour annoyance free frequency ranges from a high of 99% to a low of 91%. The setback distance is in the downwind prevailing wind direction that would be the worst case scenario. The separation distances for other wind directions can be adjusted by the weather stability and wind conditions. The dispersion area is assumed to be flat and the effect of other topography is not considered.

The dispersion model has been validated for short-distance (50 to 400 m) (Zhu et al. 2000) and long-distance (0.4 to 3.2 km) with extensive field odour measurements (Guo et al. 2002).

The significant difference between OFFSET and the other setback guidelines is that the separation distance is obtained by an air dispersion model with actual odour emission and weather data rather than empirical formulae.

Table 3 summarizes the main features of the five models.

Swine farms

A total of thirteen swine farms in Minnesota was used for the model comparisons. Seven farms (farms 1 to 7) were small to medium sized pig farms located in a 4.8 km x 4.8 km grid in a southern Minnesota county. Odour events were monitored in the grid by nineteen persons, who lived from 0.16 to 4.8 km from the farms, from June to November in 1999 (Guo et al. 2002). The other six (farms 8 to 13) were larger swine farms and had received odour complaints from neighborhood residents via the Minnesota Pollution Control Agency (MPCA). The types and numbers of pigs and odour sources for these farms are summarized in Table 4.

Assumptions for separation distance calculation

1. The farms were located in Minnesota and average weather conditions for the state were used for OFFSET model calculation.
2. The area was flat, therefore, the influence of topography was not considered in the calculation and comparison.
3. Animals were fed “dry” feed.
4. Shallow manure pits were used for farms with outside manure storage basins while deep manure pits were used if there were no outdoor manure storages.
5. All barns were mechanically ventilated.
6. No odour control technologies were used for barns or manure storages.
7. The total odour emission factors in Table 4 and the total odour emission values used in the method of W-T model were estimated by using Table 1.

Table 2. Weather influence factors with various odour annoyance free frequencies

Weather condition	1	2	3	4	5	6
Weather stability class	F	F	E	E	D	D
Wind speed (m/s)	1.3	3.1	3.1	5.4	5.4	8.0
Odour annoyance free frequency for Minnesota (%)	99	98	97	96	94	91
a	1.685	0.729	0.446	0.180	0.131	0.051
b	0.513	0.537	0.540	0.584	0.583	0.626
r^2	0.998	0.998	0.996	0.995	0.999	0.997

Table 3. Summary of features of the five models.

	MDS-II	W-T	Austrian	Purdue	OFFSET
Principle	Empirical	Empirical	Empirical	Empirical	Dispersion model
Emissions estimation	Emissions not estimated	Need actual emissions	Emissions not estimated	Animal number and average emission factors for buildings and manure storages	Average surface area emissions for buildings and manure storages
Outdoor manure storage	Yes	Yes	No	Yes	Yes
Animal species	All	All	All	Pigs	Pigs. dairy, beef, poultry
Odour control credits	N/A	N/A	N/A	0.3 - 1.0	0.1 - 1.0
Topographic feature	N/A	N/A	0.6 - 1.0	0.8 - 1.0	N/A
Land use	0.2 - 2.0	N/A	0.5 - 1.0	0.5 - 1.0	91 to 99% annoyance free
Multiple sources	N/A	N/A	N/A	N/A	Yes
Multiple wind direction	N/A	N/A	N/A	Yes, wind frequency factor	Yes, wind frequency and atmospheric stability class
Model validation	Not formally	Yes (survey)	No	No	Yes
Ease of use	Relatively easy, some interpretation needed	Knowledge needed to chose factors	Need to measure emissions	Knowledge needed to chose factors	Relatively easy, some interpretation for housing types needed

Table 4. Information about the swine farms.

Farm	Animal	Odour source		Total odour emissions factor (x 10^4)
		Building (m^2)	Outside manure storages	
1	960 nursery to finishing	4 barns (735)	None	30
2	1720 finishing	2 barns (1637)	None	60
3	1870 nursery to finishing	4 barns (1683)	None	60
4	2500 nursery/finishing	7 barns (2725)	None	101
5	750 sows	2 barns (1869)	1 lagoon (91 x 91 m)	130
6	600 sows, 2500 nursery/finishing	6 barns (3450)	1 earthen basin (31x 38 m)	143
7	1300 sows, 4000 nursery	3 barns (4167)	2 earthen basins (58x 58 m, 58 x 61 m)	185
8	2000 nursery, 1000 sows	3 barns (3534)	1 earthen basin (61 x 61 m)	160
9	1300 sows farrowing to weanling	3 barns (3348)	2 earthen basins (61 x 48 m, 61x 61 m)	180
10	1400 sows, 2800 nursery	4 barns (4508)	2 earthen basins (48 x 48 m, 48 x 76 m)	228
11	2400 sows farrowing to weanling	3 barns (6882)	1 tank (1116 m^2), 1 basin (61 x 76 m)	283
12	4600 sows farrowing to weanling	6 barns (13,020)	2 tanks (1116 m^2), 1 basin (61 x 122 m)	480
13	3500 nursery, 3500 finisher	5 barns (4185)	2 earthen basins (61 x 152 m, 61 x 305 m)	500

Table 5. Setback distances (m) determined by the five models.

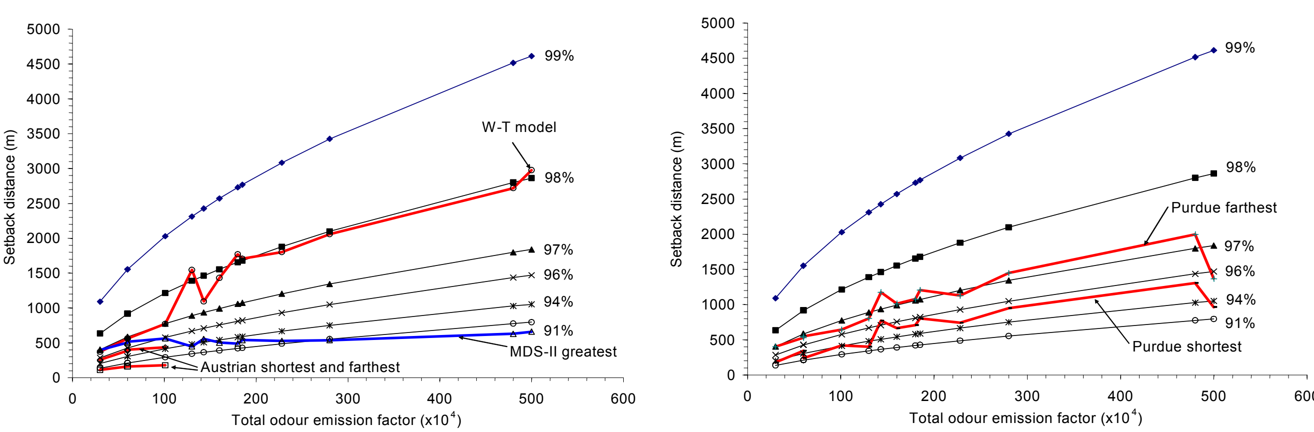
Farm	Minnesota OFFSET						Purdue		W-T Model	Austrian		MDS-II farthest
	99%	98%	97%	96%	94%	91%	farthest	shortest		farthest	shortest	
1	1089	633	402	284	204	137	402	177	370	257	113	397
2	1554	918	585	426	306	211	531	346	563	386	161	503
3	1554	918	585	426	306	211	550	241	563	402	161	517
4	2030	1214	775	578	414	293	644	418	772	434	177	564
5	2310	1390	888	670	480	343	805	402	1545			450
6	2426	1463	935	708	508	364	1175	772	1094			555
7	2769	1680	1074	823	590	428	1207	805	1706			540
8	2570	1554	993	756	542	390	1014	663	1432			503
9	2730	1655	1059	810	580	420	1078	708	1770			489
10	3082	1879	1203	930	666	487	1126	740	1802			528
11	3425	2098	1344	1048	751	554	1448	949	2060			538
12	4517	2802	1797	1436	1028	777	1998	1308	2719			631
13	4612	2864	1837	1471	1053	797	1368	965	3829			660

RESULTS and DISCUSSION

Table 5 and Fig. 1 give the setback distances obtained by the five methods for the swine farms. For MDS-II model, only the farthest distances were given when Factor E was 2. The shortest and farthest distances by the Austrian model were obtained by considering f_D as 0.6 and 0.7, and f_L as 0.5 and 1.0, respectively. For the Purdue model, the shortest and farthest distances were obtained by considering the land use factor L as 0.5 and 1.0 and building orientation and shape factor V as 1.00 and 1.15, respectively.

To make the graph more readable, Fig. 1 presents two graphs which use OFFSET setback curves as the base curves with which the setbacks generated by other models are compared. The farms can be found on the x axis by their total odour emission numbers. The setback distances generated by different models can be found on the y axis for every farm.

The largest setback distances were generated by OFFSET's 99% odour annoyance free frequency level as seen in Table 5 and Fig. 1. OFFSET's distance for 98% level is similar to that produced by the W-T model (Fig. 1 a). The Ontario's MDS-II model and the maximum and minimum ranges for the Austrian model resulted in the smallest setbacks (Fig. 1 a). The MDS-II model produced distances that were between OFFSET's setbacks for 94% and 91% frequency levels for small to medium sized farms and lower than OFFSET's 91% distances for large sized farms. The curve is quite flat and the differences of setback distances are not great for different sizes of farms. Since the large farms all had outside manure storage units and the Austrian model does not have the capability to include that type of odour source, it was excluded for these operations. For the farms without outdoor manure storages, the Austrian model's "farthest" distance is between the setbacks of OFFSET 91% and 94% frequency levels while its "shortest" distance is less than that of the OFFSET's 91% level. As shown in Fig. 1 b), the Purdue model's "farthest" case is about that determined by OFFSET's 97% level while its shortest distances are similar to those determined by OFFSET's 94 to 96% levels.



(a) W-T, Austrian, and MDS-II models vs OFFSET model **(b) Purdue model vs OFFSET model**

Fig. 1. Setback distances obtained by different models for the swine farms (91 to 99% curves are obtained by OFFSET model).

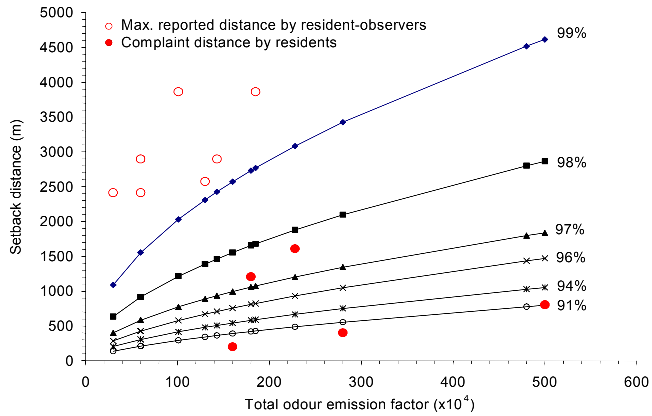


Fig. 2. Reported detection distances and OFFSET setback distances.

Data obtained from the study done by Guo et al. (2002) are shown in Fig. 2 giving the farthest distances that resident odour observers reported odours from for farms 1 to 7. Figure 2 also gives the distances between the farms and the neighborhood residents who complained to MPCA about swine odours for farms 8 to 13 in 1999 and 2000. For farms 1 to 7, the actual detected distances of odours by residents were all greater than the setback distances determined by the OFFSET model at 99% odour annoyance free levels. There are two reasons. First, the annoyance free odour intensity of OFFSET was set at "faint odour", i.e. 75 OU, instead of very faint or no odour. For some residents living farther than the setbacks of OFFSET's 99% level, they might detect odours. However, the odours would have lower intensity (very faint odour) and the odour occurrence frequency and intensity would be considered acceptable according to the OFFSET model. Second, the odour annoyance free frequency was set at 99% instead of 100%, therefore, there was still 1% of the time odour might exceed 75 OU. All the odours reported by the resident-observers in Fig. 2 were odours of intensity 1, however, they used a simplified 3-point intensity scale in which intensity 1 included intensity 1 (very faint) and 2 (faint) on a 5-point intensity scale (Guo et al. 2002). It was unknown whether the odours detected were intensity 1 or intensity 2 on a 5-point scale. It was also very difficult to obtain odour occurrence frequencies resultant from these farms for these odour-observers because there were some other livestock farms upwind of the odour-observers.

The distances between the residents who complained to MPCA and the swine farms were between OFFSET 97% and 98% curves for Farms 9 and 10, and at or below OFFSET 91% curve for Farms 8, 11, and 13. Therefore, the complainants would experience more or less odours depending on the annoyance free frequencies at their locations. The expected odour occurrence frequency would be 2 to 3% for farms 9 and 10, and 9% or higher for farms 8, 11, and 13.

Scientific background of the models

The Ontario MDS-II, Austrian, and Purdue models are empirical models based on factors generated by people who have had practical experience determining setback distances. MDS-II model only considers the odour production potentials and does not consider factors that affect odour dispersion and neighboring land use. In contrast, the W-T model, from the Warren Spring Laboratory in England is also an empirical model but is based on actual odour emission measurements. Although Williams and Thompson developed dispersion models and calculated odour concentration downwind of the source, which were found to compare well with the empirical model, the dispersion models were not used in the setback distance determination. The setback distances were decided by comparing the calculated odour concentration with related odour complaints. The main limitation of using odour complaints to judge the separation distances is that the complaint distance is highly dependent on the number of neighbors, the locations of the neighbors, and the sensitivity and acceptability of the neighbors to the odours. Also, the setback distance of this W-T model is the maximum distance from the odour source.

The OFFSET model is the only model discussed in this paper that calculates odour concentrations at various distances from an odour source by a dispersion model. It also determines the separation distances according to the odour intensity level and desired odour annoyance free levels based on historical weather data. It is capable of providing different setback distances for various odour annoyance free levels surrounding the farm regarding the locations of the residences and the local weather data. It is also the only model that can take into account multiple sources. OFFSET does not consider the influence of topography; therefore, a scaling factor needs to be developed for implementing the OFFSET in areas with various landscapes.

Odour annoyance free criteria of the models

Two of the most important aspects of odours when determining the annoyance free criteria for odour nuisance are odour frequency and intensity. To set an odour annoyance free criteria, it is important to decide what odour intensity is the threshold for annoyance or nuisance, i.e. odour annoyance level, and how often people can endure odours equal or stronger than this odour intensity level. In other words, how often people should be free from the odours equal or greater than the odour annoyance level, i.e. odour annoyance free frequency. For the OFFSET model, the odour annoyance level is clearly set at intensity 2 (faint odour) on a 0 to 5 intensity scale and the annoyance free frequency varies from 91% to 99%. The setback distances can be chosen regarding different odour annoyance free requirements of the neighborhood. The neighbors are aware of how often they can expect odours with this odour intensity or higher. This is a feature that the other models do not possess. The other models, for example, MDS-II, Purdue, and Austrian models, employ a land use factor to reflect the sensitivity of neighbors to livestock odours.

Odour emission estimations

As mentioned previously, with the diversity of manure handling systems and facility designs and the new odour control technologies currently being developed, animal number is not the only variable in determining the amount of odour emissions. Total odour emissions from different farms with a similar number of animal species can be quite different (Guo et al. 2002).

An obvious shortcoming of the Austrian model is that it does not consider the odour emissions from outdoor manure storage units. A new model has been reported by the same authors (Schauberger et al. 2000) which includes manure storage sources and also uses a dispersion model, but not enough information was provided to include it in this comparison. All other models did allow for the inclusion of the important manure storage unit sources on animal production sites.

The estimation of odour emissions was not done in either the MDS-II or Austrian models. The MDS-II model selected a “barn odour potential” factor by animal species plus an additional factor for liquid or solid manure system that indirectly accounted for different odour emissions. The Austrian model assessed odour emission indirectly by the animal metabolism via the species and weight, together with ventilation, manure handling, and feed management factors. Every factor has a wide range, and there are no detailed criteria for how to choose the factor making the process rather subjective. For instance, animal factor f_A for pigs is in the range of 0.1 to 0.33, feed management factor for liquid feed is 0.05 to 0.20, and ventilation factor for mechanical ventilation ranges from 0.10 to 0.45, etc.

The Purdue model considers odour emissions from both buildings and outdoor storages. Odour emissions from buildings are estimated by odour emission factors regarding pig number and weight. The emission factors are based on the amount of manure production from various stages of pig production. Odour emissions from outdoor storage units are estimated from the assumption that every animal unit (500 kg) produces an emission rate of 50 OU/s. An odour abatement factor is considered, varying numerically from 0.3 to 1. Manure storage basins and manure treatment lagoons vary greatly from farm to farm and it is rather difficult to make a proper judgment for the odour abatement factor.

It does seem reasonable that separation distance should be based on actual odour emissions instead of indirect quantities such as animal numbers, manure production, etc. Also, since it is not practical to measure odour emissions from every farm, it is reasonable to use the average odour emissions of various sources in a certain area to make the appropriate estimation as used in both the Purdue and Minnesota OFFSET models.

SUMMARY and CONCLUSIONS

Five setback models, based on experience, combination of empirical and odour measurement, or odour dispersion calculation, were discussed and compared for various sizes of swine farms. The setback distances generated by different models fell into a wide range. The largest setback distances were generated by OFFSET’s 99% odour annoyance free frequency level. The Williams and Thompson model (W-T model), from the Warren Spring Laboratory in England, gives setbacks similar to OFFSET 98% odour annoyance free distance. The Purdue model produced medium setback distances similar to 94 to 97% annoyance free level of the OFFSET model. The Austrian model does not consider outdoor manure storage units. Its “farthest” distance was between the setbacks of OFFSET 91% and 94% frequency levels while its “shortest” distance was less than that of the OFFSET’s 91% level. The setback distances determined by the MDS-II model fell in a narrow range and were between OFFSET’s setbacks for 94% and 91% frequency levels for small to medium sized farms and less than OFFSET’s 91% distances for larger sized farms.

Using the OFFSET model, the odour occurrence frequencies at neighboring odour observers or complainants’ locations were identified. The OFFSET model demonstrated an approach to set science-based setback distances from livestock operations. Since the difference might be as much as ten times between the closest and farthest setback distances determined by different models, it is critical that a suitable model is chosen and the information into the components of the model is known, especially if used by local government units or others for land use decision-making.

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