Development of the OFFSET Model for Determination of Odor-Annoyance-Free Setback Distances from Animal Production Sites: Part II. Model Development and Evaluations

H. Guo, L. D. Jacobson, D. R. Schmidt, R. E. Nicolai, J. Zhu, K. A. Janni

Abstract. *The OFFSET (Odor from Feedlots − Setback Estimation Tool) model was developed to estimate the setback distances from animal production sites in Minnesota. It is based on odor emissions taken from field measurements and an evaluated air dispersion model. The odor emissions of a site were estimated using odor emission rates that were the geometric means of odor emissions measured from 280 animal buildings and manure storage units on 85 farms in Minnesota. The odor-annoyance-free intensity level was set at 2 (faint odor) on a 0 (no odor) to 5 (very strong odor) intensity scale. An evaluated air dispersion model, INPUFF-2, was used to calculate setback distances from various animal farms for the set odor-annoyance-free level under six weather conditions that favor odor transport. Setback distances are presented in a graphic form as well as mathematically as a function of the total odor emission factor and the desired odor-annoyance-free frequency of the neighbors. Odor-annoyance-free frequencies between 91% and 99% are based on the average weather data for Minnesota from 1984 to 1992. Suggestions for odor-annoyance-free frequency selections are given. The OFFSET model also deals with residences located in different directions from a livestock site. Additionally, it can determine the odor occurrence frequency of a residence surrounded by several livestock sites. Comparing the setback distances obtained from the OFFSET model and the odor events reported by the resident observers, it was found that the OFFSET model does not overpredict odor transport distances under very stable weather conditions. By comparing the OFFSET predictions with the odor complainers' distances from swine farms, it was clear that their residences had high odor occurrence frequencies. The OFFSET model was also evaluated by comparing odor occurrences documented by the resident odor observers in the vicinity of eight livestock farms. It was found that although the model may describe the average neighborhood intensity correctly, a high variation in the observed odor intensities existed for all levels of predicted intensities calculated from the OFFSET. Further research is needed to improve the accuracy of OFFSET and also to improve the field odor measurement method by the resident observers to obtain reliable odor occurrence data. By comparing OFFSET with four other existing setback guidelines, it was found that the distances required by the other models fell in or below the 91% to 98% annoyance-free curves of the OFFSET.*

Keywords. *Animal, Dispersion, Distances, Emission, Evaluation, Modeling, Odor, Separation.*

The objective of this study was to develop a science-based method to establish setback distances from animal production sites, based on the use of an air dispersion model that uses actual odor emission data, the selected odor-annoyance-free odor concentration, and historical weather data for Minnesota. The companion report, i.e., Part I of this study, described the separation distance determination approach and some experimental results (Jacobson et al., 2005). Typical odor emission rates for various livestock production facilities in Minnesota were measured from 280 animal buildings and manure storage units on 85 farms in Minnesota. The geometric means of the measured odor emissions were used to estimate emissions from other similar systems. The relationship between odor intensity and the odor detection threshold was determined in order to convert downwind odor intensity to odor threshold for the purpose of dispersion model evaluation. An air dispersion model, INPUFF-2 (Bee-Line Software Co., Asheville, N.C.), was evaluated by downwind odor plume measurement using trained field odor assessors and resident odor observers. It was proven reliable for prediction of odor dispersion from livestock operations. The frequencies of six different weather conditions that favor odor transport were calculated based on weather data from six weather stations in Minnesota from 1984 to 1992 (Jacobson et al., 2005).

Article was submitted for review in July 2004; approved for publication by the Structures & Environment Division of ASABE in November 2005. Presented at the 2000 ASAE Annual Meeting as Paper No. 004044.

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Part II of this report describes how the OFFSET (Odor from Feedlot − Setback Estimation Tool) model was developed by calculating the required setback distances using the INPUFF-2 dispersion model based on the total odor emission rates for various weather conditions and the desired odor-annoyance-free intensity and frequencies. Finally, OFFSET results were evaluated against available field odor measurement data.

Assumptions in the OFFSET Model

The assumptions that are used in the INPUFF-2 model to produce the setback distances required by the OFFSET model are discussed in the following sections.

Source Emissions

Only one animal production site is considered in the odor dispersion simulation by INPUFF-2. Multiple sites are discussed later in the Considerations of Multiple Sites section.

Odor emission rates for various odor sources at a site were estimated using odor emission numbers that are the actual odor emission rates multiplied by a scaling factor (35 for building sources, and 10 for manure storage units). Tables 2 and 3 of Part I (Jacobson et al., 2005) list the odor emission numbers for various animal housing systems and manure storage facilities. The total area of a building or manure storage basin is used as the source area of odor emission, and the odor emission rate over the area is assumed to be uniform. The area is then converted to a circular area as a point source to be used in the INPUFF-2 model.

Typical site setups for various livestock operation sizes and multiple odor sources are considered in odor dispersion simulation using the INPUFF-2 model.

Odor emissions during the calculation period are considered constant.

The total odor emission rate of a site is described by the total odor emission factor, which is the sum of the total odor emission numbers of all odor sources of the site. It is calculated by:

$$E = \sum_{i=1}^{n} E_i = \sum_{i=1}^{n} \left(E_{ei} \times A_i \times f_{ci} \right) \qquad (1)$$

where

- E = total odor emission factor from an animal production site (dimensionless)
- E_i = odor emission from source i (dimensionless)
- i = 1 to n, where n is the total number of odor sources
- E_{ei} = odor emission number of source i on a per square meter basis, ranging from 11 to 530 for various buildings and manure storage facilities
- A_i = area of source i (m^2)
- f_{ci} = odor control factor of source i, varying from 0.1 to 0.6 for different odor control technologies such as biofilters, various basin covers, and oil sprinkling, as given in table 4 of Part I (Jacobson et al., 2005). If no odor control technology is incorporated, then f_{ci} = 1.

Topography

The calculated area is assumed flat with no obstructions; thus, no topographical changes are considered.

Weather Conditions

Six different weather conditions, from stable to neutral, are considered as follows:

- Stability F with wind speed 1.3 m/s, represented by W1 or F, ≤1.3 m/s
- Stability F with wind speed 3.1 m/s, represented by W2 or F, ≤3.1 m/s
- Stability E with wind speed of 3.1 m/s, represented by W3 or E, ≤3.1 m/s
- Stability E with wind speed of 5.4 m/s, represented by W4 or E, ≤5.4 m/s
- Stability D with wind speed of 5.4 m/s, represented by W5 or D, ≤5.4 m/s
- Stability D with wind speed of 8.0 m/s, represented by W6 or D, ≤8.0 m/s

The wind field of the calculated area is homogeneous, the ambient temperature is 20°C, and the weather conditions remain constant during each 2 h simulation period.

Odor-Annoyance-Free Criterion

The odor-annoyance-free level was defined as 75 OU or an intensity of 2 (faint odor) on a 0-to-5 n-butanol intensity scale (Guo et al., 2001). An odor with intensity equal or lower than 2 is considered acceptable in terms of nuisance concern. The desired odor occurrence frequency is determined by the users when they select the setback distances given by the OFFSET model.

Receptor and Setback Distance

The setback distance is the downwind distance of a livestock production site where the odor concentration is 75 OU, i.e., the set odor-annoyance-free criterion of intensity 2 (faint odor) on a 0-to-5 n-butanol intensity scale (Guo et al., 2001). Beyond this distance, odor concentration is less than 75 OU, while within this distance, odor concentration is greater than 75 OU.

Other Assumptions

Odor dispersion is calculated for 2 h.

Odor and gas deposition and chemical reaction are neglected.

The source height for buildings is 1.5 m, which is the average height of exhausting fans or curtains. The source height for manure storage units is at the ground level, i.e., 0 m.

OFFSET Setback Distance Determinations

The setback distances of the OFFSET model calculated using INPUFF-2 for the six weather conditions selected are shown in figure 1. The total odor emission rate of a site is the total odor emission factor, which is the sum of the odor emission numbers of all odor sources of the site. In figure 1, the horizontal axis is the total odor emission factor of an animal production site divided by 10^4, which ranges from 5 to 500 for small- to large-sized animal production operations.

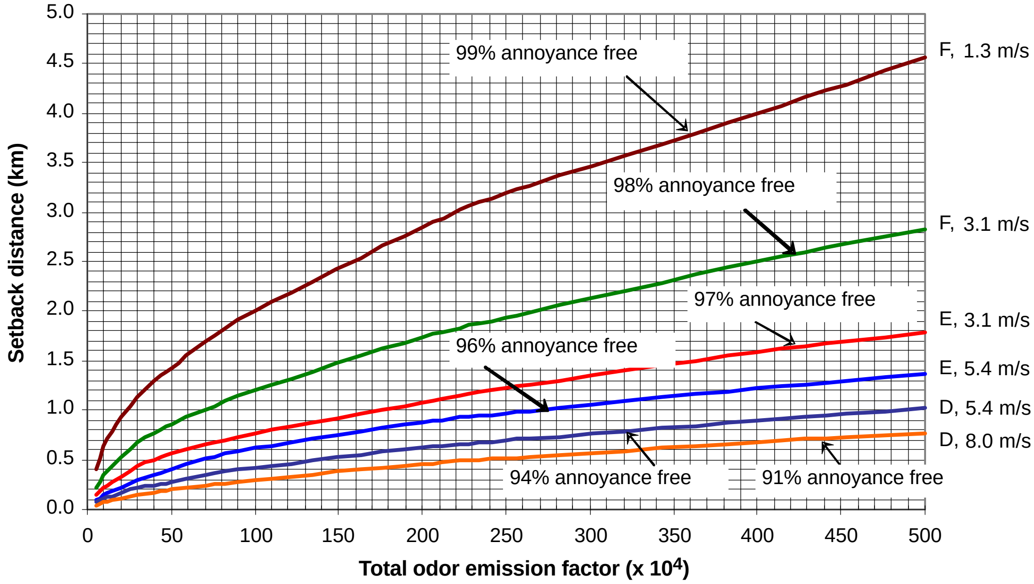

Figure 1. Setback distances for different weather conditions from animal production sites. The odor-annoyance-free frequencies are the averages for Minnesota. Weather conditions given are atmospheric stability class and wind speed.

The vertical axis is the separation distance in kilometers. The family of curves gives the distances at which the odor concentration is 75 OU for six different weather conditions, as marked on the right side of the graph. The OFFSET model assumes that the receptor is located downwind from a livestock site in any of the 16 directions. The odor-annoyance-free frequencies in various directions for these six weather conditions can be determined by the windstar chart of the area of interest.

The frequency curves represent the odor-annoyance-free time downwind of the prevailing winds from an odorous site. The frequencies marked on the curves in figure 1 are 99%, 98%, 97%, 96%, 94%, and 91%, corresponding to the average non-occurrence frequencies of the six weather stations in the worst cases in Minnesota during 1984 to 1992, as discussed in Part I (Jacobson et al. 2005). These frequencies are equivalent to the accumulated times of 7, 14, 22, 29, 43, and 65 h per month. For example, 99% annoyance-free means 99% of the time, at the distance shown on the curve downwind of a prevailing wind from the site, the residents are not expected to receive an odor that exceeds an odor intensity level of 2. However, during the rest of the time (1%, or 7 h per month), the residents may experience odor equal to or higher than the "annoyance-free" level of 75 OU. For residents located farther than the distances shown on the curves, the odor-annoyance-free levels will be higher than the curve values. If residents are located closer than the distances shown on the curves, then high-odor frequencies may be expected.

Because the six weather conditions that favor odor transport mostly occur at night, at early morning, and/or at evening, odors would most likely be detected at these times, when odors can travel easily due to very low wind speeds and stable weather conditions.

If a windstar chart is available, as shown for Minneapolis/St. Paul in figure 1 of Part I (Jacobson et al., 2005), then setback distances for each of the 16 compass directions can be found to meet different odor-annoyance-free requirements. The highest odor frequencies for the 16 directions for the six weather conditions are 0.7%, 1.5%, 1.9%, 2.5%, 5.0%, and 6.9%, respectively. The remaining frequencies are odor-annoyance-free frequencies, which are 99.3%, 98.5%, 98.1%, 97.5%, 95.0%, and 93.1%, respectively.

The separation distance and the total odor emission factor are correlated in a power relationship as (r^2 = 0.995 to 0.998):

$$D = aE^b \qquad (2)$$

where

D = separation distance (m)

a, *b* = weather influence factors for various odor frequency requirements, dimensionless. Values are given in table 1.

It must be noted that uncertainties exist in the calculated separation distances due to the assumptions made in the calculation, as stated previously, and a number of other error sources such as the uncertainty of the source emission rate measurement, the uncertainty of odor dispersion prediction by INPUFF-2, and variations in the olfactory sensitivity of the receptors. Due to the complexity of the error sources, it is difficult to give the uncertainties of the calculated distances. This will be further discussed later in Evaluation of the OFFSET Model.

Table 1. Weather factors for various odor-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
Odor-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

SETBACK DISTANCE DETERMINATION PROCEDURE USING OFFSET

On the basis of the above studies, the OFFSET model was developed to estimate the separation distance for animal production operations. This tool is intended to be used to estimate setback distances from an animal production site that satisfy various odor-annoyance-free frequencies. The OFFSET model accounts for species, housing types and sizes, manure storage types and sizes, and odor control technologies used at a site. In order to use OFFSET for a specific area, in addition to the farm data, two other basic pieces of information are needed: odor emission data for the odor sources, and a windstar chart for the location. The following is a step-by-step process for determining the setback distance using figure 1 according to the desired odor-annoyance-free level:

Step 1: Identify all odor sources on the site and determine the total odor emission factor of the site using equation 1, as described in the Source Emissions section.

Step 2: Determine the odor-annoyance-free frequencies of the six curves in figure 1 or table 1. The occurrence frequencies of the six weather conditions in the direction of interest or all 16 directions can be determined based on the local windstar. For each weather condition, the non-occurrence frequency, i.e., 1 minus the occurrence frequency, gives the odor-annoyance-free frequency of the corresponding curve in figure 1 or table 1.

Step 3: Determine the setback distance needed for the total odor emission factor to meet the desired odor-annoyance-free frequency for the surrounding area using figure 1 or equation 2 and table 1.

OFFSET Demonstration Example

A typical 1200-head sow gestation and farrowing operation with mechanical ventilation and pull-plug gutters and a single-stage earthen basin in Minnesota is outlined in figure 2.

The total odor emission factor from the site is 171.9×10^4. According to figure 1, there are different distances from the source depending on the different odor-annoyance-free frequencies. At 2.6 km, the odor will be at or below an annoyance free level 99% of the time. The rest of the time, i.e., 1% of the time or 7 h in a month, a "faint" odor at intensity 2 or stronger may be detected. If 98% odor-annoyance-free is desired (14 h in a month), the setback distance could be 1.6 km. For the other "odor-annoyance-free" curves shown (97%, 96%, 94%, and 91%), annoying odors might occur 3%, 4%, 6%, and 9% of the time, which would result in corresponding setback distances of 1.0, 0.8, 0.6, and 0.4 km, respectively.

For discussion purposes, assume several families live 0.8 km away from the site and the producer wants to modify the facility by adding odor control technologies that will result in a smaller setback distance. The producer chooses to add a biofilter (odor control factor of 0.1) to the two buildings and a geotextile cover (odor control factor of 0.5) to the basin. The total odor emission factor for the modified production site is reduced to 38.2×10^4. Only the 99% annoyance-free curve would not be reached by a 0.8 km setback, and that would probably satisfy the goal. There would be an additional cost to the producer for these odor control measures, but that cost could be weighed against the expenses incurred in trying to find an alternative site.

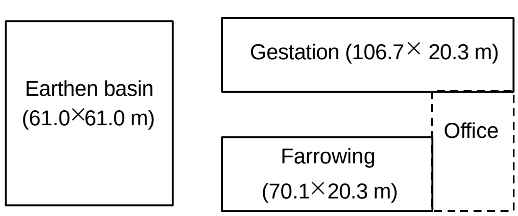

Figure 2. Outline of a 1200-sow gestation-and-farrowing operation.

DISCUSSIONS OF OFFSET APPLICATION

CONSIDERATION OF DIFFERENT DIRECTIONS FROM AN ANIMAL PRODUCTION SITE

To use OFFSET, the receptor can be located downwind from the odor source in any of the 16 compass directions. Let us assume the example farm discussed above without odor control technologies is located in the Minneapolis area. According to the windstar chart of this area given in figure 1 of Part I (Jacobson et al., 2005), the highest occurrence frequencies of the six weather conditions in all directions in this area are 0.7% from SW for weather condition W1, 1.5% from SW for W2, 1.9% from SW for W3, 2.5% from SW for W4, 5.0% from ESE for W5, and 6.9% from NW for W6. The required setbacks are between 0.4 km for W6 or annoyance-free frequency of 93.1% to 2.6 km for W1 or annoyance-free frequency of 99.3%. If a receptor lives 2.6 km in the northwest direction away from the farm, then 99.3% of the time this location will be odor-annoyance-free. Since this direction has the highest occurrence frequency for this weather condition among the 16 directions, all the other neighboring areas at the same distance from the animal site but located in non-northwest directions from the farm, i.e., non-prevailing wind directions, will have odor-annoyance-free levels higher than 99.3%. The highest odor-annoyance-free level is 99.9% from SSW to W of the site because occurrence frequency of weather condition W1 with winds from NNE to E is only 0.1%.

Similarly, the highest frequency for weather condition W2 is 1.5% from the SW direction. The required setback distance is 1.6 km for this weather condition. The setback should be 1.6 km if the residence is located northeast of the site in order to get an odor-annoyance-free level 98.5%. All other locations at the same distance from the site will have a higher odor-annoyance-free frequency. The area SSW of the site has the lowest odor-annoyance-free level, a level of 99.8% (frequency for W2 from NNE direction is 0.2%). Therefore, even though the distances of two separate residences from a particular livestock site might be the same, by locating one of them in a different direction from the animal production site, the odor-annoyance

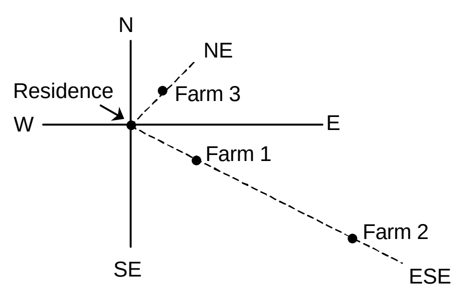

Figure 3. An example of a residence in the neighborhood of three animal farms.

Table 2. Odor annoyance-free frequency determination for multiple animal production farms around a residence.

Farm	Total Odor Emission Factor ($\times 10^4$)	Distance (km)	Corresponding Weather Condition	Odor Occurrence Frequency (%)	Odor-Annoyance-Free Frequency (%)
1	100	0.8	W3 (E, ≤3.1)	1.7 (W3 from ESE)	98.3
2	400	2.6	W2 (F, ≤3.1)	1.1 (W2 from ESE)	98.9
3	170	0.6	W5 (D, ≤5.4)	1.8 (W5 from NE)	98.2
1 + 3				3.5 (= 1.7 + 1.8)	96.5
2 + 3				2.9 (= 1.1 + 1.8)	97.1
1 + 2			W4 (E, ≤5.4)	2.3	97.7
1 +2 +3				4.1 (= 2.3 + 1.8)	95.9

ance-free level may be quite different. The highest occurrence frequencies of the other four weather conditions are 1.9% for W3 from SW, 2.5% for W4 from SW, 5.0% for W5 from ESE, and 6.9% for W6 from NW to N and S to ESE directions.

Considerations of Multiple Sites

The OFFSET model also has the ability to consider the impact of odors from multiple animal production sites on a particular receptor if the windstar chart is available. For example, if a residence near Minneapolis/St. Paul is located near three animal production sites, as shown in figure 3, the total odor emission factors of these three farms are given in table 2.

The distances from the residence to farms 1 and 3 meet the odor-annoyance-free requirements for weather conditions W3, W2, and W5, respectively. The odor frequencies for weather conditions W3 and W2 in the ESE direction are 1.7% and 1.1%, respectively, and that of W5 from NE is 1.8%. Hence, this residence has odor-annoyance-free frequencies of 98.3%, 98.9%, and 98.2% from each farm separately (assuming that only one farm exists in each case).

If there were only farms 1 and 3 (assuming farm 2 does not exist), then the frequency of odor occurrence is the accumulation of those two farms, i.e., 3.5%, because the two farms are in different directions from the residence. The odor-annoyance-free frequency would be 96.5%. Similarly, if there were only farms 2 and 3, the odor-annoyance-free frequency would be 97.1%.

However, if there were only farms 1 and 2 (assuming that farm 3 does not exist), then the odor-occurrence frequency at the residence would be less than that of the two frequencies added together. Since these two farms are located in the same direction from the residence, the frequency of W3 (stability E and wind speed ≤3.1 m/s) includes the frequencies of W1 and W2 (stability F). The odor concentration at the residence might be equal to or greater than 75 OU when the weather is more unstable than W3. For example, under W4, although odor from each of the farms separately would not result in 75 OU at the residence, the total odor concentration caused by both farms might reach 75 OU or higher. Therefore, the frequency of odor concentration equal to or greater than 75 OU would be higher than the frequency of W3, i.e., 1.7%. In this case, with more than one farm in the upwind direction, the INPUFF-2 model needs to be used to determine the weather condition necessary for obtaining 75 OU at the residence. For this example, the odor-annoyance frequency at the residence could be estimated by the next weather condition W4, which occurs 2.3% of the year. Thus, the odor-annoyance-free frequency would be 97.7% as a combined effect of farms 1 and 2. The odor-annoyance-free frequency as a result of all three farms would be 95.9%.

Consideration of Land Use

The separation distance varies greatly with different requirements for annoyance-free levels. One needs to be very careful about selecting high odor-annoyance-free frequencies, such as 99% and 98% (7 and 14 h per month possible odor occurrence). It also should be noted that odor events usually occur at night and in early morning and/or at evening, when odors can travel easily due to low wind speeds and stable weather conditions. Table 3 lists suggested odor-annoyance-free criteria for the frequencies used in OFFSET for different land use purposes. These suggested frequencies may have to be adjusted depending on the local land use and the general acceptability of livestock odors in a specific area.

Impact of Topography

Although topography affects odor dispersion, its influence has not been incorporated into the OFFSET method. The odor-annoyance-free curves given in figure 1 were obtained assuming flat terrain with no obstructions. The dispersion model (INPUFF-2) used in OFFSET does have the capability to consider topographic variations, but the model requires the input of geographic data for the simulation area. It is possible to generate setback distances including topography for a specific area using INPUFF-2; however, the result will not likely be useful for other areas because their topographies would not be the same. Hence, a practical approach is to incorporate an empirical factor considering different topographies to adjust the setback obtained by OFFSET, as used by some other setback estimation models (Schauberger and Piringer, 1997; Lim et al., 2000). For example, topographical factors for flat terrain with no trees or building obstacles could be assigned as 1 as obtained by OFFSET, flat terrain with obstacles assigned as 1.05 to increase setbacks by 5%, sites located on a hill 1.1 or valley 1.2 to increase setbacks by 10% or 20%, etc. Further research is needed to assign proper topography factors and collect geographical data for the areas being studied.

Table 3. Odor-annoyance-free frequencies suggested criteria for different land uses.

Odor-Annoyance-Free Frequency	Neighborhood Description
99%	Cities with more than 5,000 population, hospitals
98%	Cities with fewer than 5,000 population
97%	Residential area with 50 residences or more, churches, parks
96%	Residential area with fewer than 50 residences, churches
94%	Fewer than five rural residences
91%	Fewer than two rural residences

Table 4. Information on the swine farms.

Farm	Animal	Odor Source: Building	Odor Source: Outside Manure Storages	Total Odor Emission Factor (× 10^4)
1	960 nursery to finishing	4 barns (735 m^2)	None	30
2	1720 finishing	2 barns (1,637 m^2)	None	60
3	1870 nursery to finishing	4 barns (1,683 m^2)	None	60
4	2500 nursery/finishing	7 barns (2,725 m^2)	None	101
5	750 sows	2 barns (1,869 m^2)	1 lagoon (91 × 91 m^2)	130
6	600 sows, 2500 nursery/finishing	6 barns (3,450 m^2)	1 earthen basin (31 × 38 m^2)	143
7	1300 sows and 4000 nursery	3 barns (4,167 m^2)	2 earthen basins (58 × 38 m^2, 58 × 61 m^2)	185
8	2000 nursery, 1000 sows	3 barns (3,534 m^2)	1 earthen basin (61 × 61 m^2)	160
9	1300 sows farrowing to weanling	3 barns (3,348 m^2)	2 earthen basins (61 × 48 m^2, 61 × 61 m^2)	180
10	1400 sows and 2800 nursery	4 barns (4,808 m^2)	2 earthen basins (48 × 48 m^2, 48 × 76 m^2)	228
11	2400 sows farrowing to weanling	3 barns (6,882 m^2)	1 tank (1116 m^2), 1 basin (61 × 76 m^2)	283
12	3500 nursery, 3500 finisher	5 barns (4,185 m^2)	2 earthen basins (61 × 152 m^2, 61 × 305 m^2)	500

Evaluation of the OFFSET Model

As discussed in Part I (Jacobson et al., 2005), odor events were monitored by resident odor observers on a 4.8 × 4.8 km grid of farmland in Nicollet County, Minnesota. Farm information and the total odor emission factors are summarized in table 4 for farms 1 to 12. Figure 4 shows the setback distances for farms 1 to 7 as determined by OFFSET. As presented using circles, figure 4 also gives the farthest distances between the resident odor observers who detected odors and the source farms. It is obvious that the actual distances downwind of the odor sites where the odors were detected were beyond the 99% odor-annoyance-free distance. The odor intensities observed from these distances were all intensity 1 (very faint odor) or intensity 2 (faint odor). Most were under the set odor-annoyance-free intensity (intensity 2); therefore, these odors would not necessarily cause odor complaints. These data indicate that odors can be detected at great distance from an animal production site, although the odor strength may be tolerable to most people. They also indicate that the setback distances required by the OFFSET 99% odor-annoyance-free frequency do not overpredict the distances odors travel under very stable weather conditions.

Another evaluation of OFFSET was accomplished by estimating the level of the annoyance-free frequencies at odor complainers' locations for odor complaints received by the Minnesota Pollution Control Agency during 1998 (Guo et al., 2004). Odor source data for five swine farms (farms 8 to 12) that had odor complaints are given in table 4. Using the OFFSET procedures, the total odor emission factors were calculated and the setbacks determined for the various frequencies. The solid circles in figure 4 give the distances between the complaining residences and the odor sources and the odor-annoyance-free levels of the receptors' locations. Three residences were within the distances required for 91% odor-annoyance-free frequency. This indicates that OFFSET gives realistic results, as the complainers were exposed to high odor-occurrence levels. The other two residences had odor-annoyance-free frequencies ranging between 97% and 98%. Although odor might not have occurred very often, the residents might have been especially sensitive to swine odors, which resulted in the odor complaints.

Another study was conducted to further evaluate OFFSET. A comparison was made between observed odors by neighboring resident odor observers living in the vicinity of eight livestock and poultry farms in five different Minnesota counties and the odors as predicted by OFFSET (Nimmermark et al., 2003). Twenty trained resident observers participated in the study. The measurement method used by the odor observers was the same as that previously described in the long-distance odor plume measurement by the resident odor observers (Guo et al., 2001; Jacobson et al., 2005), except that a standard 0-to-5 n-butanol scale was used instead of a 0-to-3 scale (Nimmermark et al., 2003). Observations were made for five months from June through October 2001. In 309 out of 570 reported odor events, the farms participating

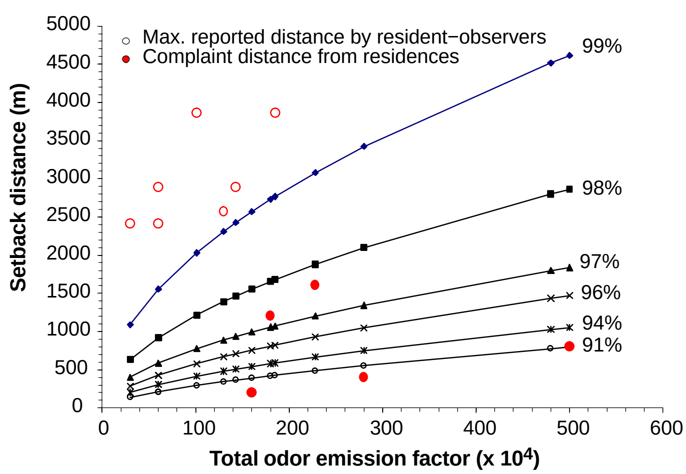

Figure 4. Reported detection distances and OFFSET-predicted setback distances.

in the investigation were the probable odor sources. In 199 (64%) of these, an odor less than intensity 2 was predicted by OFFSET, but an odor intensity equal to 2 or above was reported by odor observers. In 99 cases (32%), the predicted and reported odor intensities were in agreement, being either higher than 2 or below 2. A high variation in the observed odor intensities existed for all levels of intensity predicted by OFFSET. Regarding the observed odor intensities compared to the predicted odor intensities, considerable inter-individual as well as intra-individual variations were found.

Possible reasons for these mixed results are: (1) uncertainties in odor rating, sensitivity, and possible bias of resident odor observers (the observers were taught how to use the n-butanol scale only once at the training workshop and did not calibrate their noses afterwards during the measurement period); (2) wind speed and direction fluctuations during the 15 min data recording period; (3) errors in odor detection threshold measurement and emission calculation for barns and manure storage facilities; (4) seasonal and diurnal fluctuations in odor emissions from each farm during the experimental period from June to October (only one emission measurement was made, which could have led to great difference between the true emission and the measured value); and (5) topographic variation on the sites, since OFFSET assumes flat surfaces and some areas were in rolling terrain. The evaluation method using resident observers gave an overrepresentation of high reported values at low actual intensities, since occasions when no odor was found were not reported and since particularly odor-sensitive persons might have reported higher values than and more often than the less sensitive observers. For odor emissions from the barns, using the carbon dioxide mass balance method to obtain ventilation rates may introduce greater error than using the total airflow rate of the exhaust fans. Barn emission values used in the OFFSET model describe the average emission fairly well for many odor sources, but improvement is still needed to incorporate a management factor to represent the variations in odor emissions from different farms. For odor emissions from outdoor manure storage facilities, uncertainty may result from the estimation of real odor emission using the measured emission rate by a wind tunnel. The results indicate that OFFSET is a good estimation tool, but improvement in its accuracy should be made with better emission values, weather data, dispersion models that consider topographic and peak to mean effects, and better odor intensity measurement by field odor assessors.

Comparing OFFSET with Other Setback Models or Guidelines

Different setback estimation guidelines for animal production farms have been developed in European countries and some states and provinces in North America. Guo et al. (2004) compared five setback models, i.e., OFFSET, the Purdue model, the Ontario MDS-II model, the Austrian model, and the Williams and Thompson model, at various sizes of swine farms in Minnesota (OMAFR, 1995; MacMillan and Fraser, 2003; Schauberger and Piringer, 1997; Williams and Thompson, 1986; Lim et al., 2000, Jacobson et al., 2000). The setback distances generated by different models were found to fall into a wide range. The OFFSET model produced different setback distances according to odor-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 the 94% to 97% annoyance-free level of the OFFSET model. The Williams and Thompson model gave setbacks similar to OFFSET's 98% odor-annoyance-free distance.

As compared to the other models, the OFFSET model is science-based, takes into account different odor emission rates and weather conditions, and is based on extensive odor emission measurements, an evaluated air dispersion model, and historical weather data from Minnesota, whereas the other four models were empirical models with or without using odor emission data.

Future Work

The following work is needed to improve the OFFSET method:

- Odor emission values for various types of sources need to be improved. More measurements are needed to increase the size of the database in order to give better representative emission data. Considering the large variations in odor emission from similar sources on different farms, it may be necessary to incorporate a management factor for better odor emission estimation.
- Odor measurement and emissions calculation need to be standardized and improved, especially when the carbon dioxide mass balance method is used to obtain ventilation rates for naturally or mixed naturally and mechanically ventilated barns.
- Seasonal and diurnal fluctuations in odor emissions should be considered in the OFFSET model. For setback distance determination purpose, the maximum odor emissions may be used. However, to evaluate the model, the actual odor emission values when an odor event is detected should be used. Because obtaining the odor emission rate by actual measurement at the time of odor detection is almost impossible, seasonal and diurnal odor emission profiles and mathematical models should be obtained to better estimate odor emissions.
- Further research is needed to assign proper topography factors and to collect geographical data for the area being studied.
- For the purpose of OFFSET model evaluation, the odor measurement method used by field observers, especially resident odor observers, should be modified to ensure the quality of the data. The resident observers should be screened according to their sensitivities to odor using the same standard as that used by field odor assessors and also considering the possible bias to livestock operations of the observers. Resident odor observers should calibrate their noses regularly (for example once a day or twice a week) using the n-butanol intensity scale in order to ensure the quality of intensity readings. They also should measure odor in some designated time periods for a period of time, instead of taking only quick sniffs. For example, they should be required to go outside to measure odor for at least 10 min twice a day, once between 06:00 and 08:00 and again between 18:00 and 20:00. The measurement procedure should follow that used by the field assessors (Jacobson et al., 1998).

- For the purpose of OFFSET model evaluation, weather data should be recorded more frequently; for example, once every 5 min instead of once every 15 min, in order to more accurately capture fluctuations of wind speed and direction.

Conclusions

The OFFSET model was developed to estimate the setback distances from animal production sites in Minnesota. It was based on numerous odor-emission measurements from 280 animal buildings and manure storage units on 85 farms in Minnesota and on an air dispersion model. The geometric mean of the measured odor emission rates on an area base from each type of source was used to represent odor emissions of that type of source. The selected air dispersion model, INPUFF-2, was evaluated for short-distance (<500 m) and long-distance (up to 4.8 km) odor dispersions by extensive field odor measurements. Setback distances from animal sites were calculated by INPUFF-2, and the results were presented in graph form as well as mathematically as a function of the total odor emission factor and the desired odor-annoyance-free frequency of the neighbors. The odor-annoyance-free intensity level was set at odor intensity 2 (faint odor) on a 0-to-5 scale, or 75 OU. Different distances were chosen as required by the various odor-annoyance-free frequencies from 91% to 99% based on the historical weather data for Minnesota. OFFSET can deal with residences located in different directions of a livestock site. It can also determine the odor-occurrence frequencies of a residence surrounded by several livestock sites. Suggestions for odor-annoyance-free frequency selections were also provided.

Comparing the setbacks obtained from the OFFSET model to the distances between the locations of resident odor observers and livestock farms, odors were detected as very faint (intensity 1) or faint (intensity 2) beyond the 99% odor-annoyance-free distances. This indicated that the OFFSET model does not overpredict odor travel distances under very stable weather conditions. Comparing the distances between five odor complainers' locations and the source swine farms to the setbacks predicted by OFFSET, it is suggested that these residence locations were exposed to swine odors at a relatively high frequency and perhaps at high intensity. Based on the results of the OFFSET evaluation in eight areas in Minnesota, the OFFSET model might predict odor intensity correctly at a probability of 32%, but it tended to underpredict odor intensity for the majority of the time, as compared with the residents' responses. Further research is needed to improve the accuracy of OFFSET, especially to obtain accurate odor emission data and also to improve the field odor measurement method used by resident odor observers to obtain reliable odor occurrence data for model evaluation.

By comparing OFFSET to other existing setback guidelines, it was found that the distances required by the other four models fell in or below the 91% to 98% annoyance-free curves of OFFSET. Since the differences between the shortest and farthest setback distances determined by different models might be as much as ten times, it is critical that a suitable model is chosen and the information comprising the components of the model is known, especially if the results are to be used by local government units or others for land use decision-making.

Acknowledgement

The researchers wish to acknowledge the funding provided by the Minnesota Legislature, the Minnesota Department of Agriculture, and the Minnesota Experimental Station Rapid Agricultural Response Fund. The authors would also like to thank all other members of the odor research team at the Department of Biosystems and Agricultural Engineering, University of Minnesota, and the University of Minnesota Extension Service for their contributions to this project. Appreciation is also given to local county staff engaged in different stages of the project. Appreciation also goes to all the farmers and residents who contributed to this project.

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