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Keywords
odors, modeling, air quality, swine

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Modeling Odor Dispersion From a Swine Facility Using AERMOD

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ABSTRACT

Meteorological conditions, odor emissions, and ambient odor levels at a four-barn, swine finishing facility in Iowa were measured in the summer and fall of 2004. This paper compares ambient odor levels measured using a Nasal Ranger® compared to those predicted by AERMOD, a relatively new air dispersion model. Scaling factors needed to adjust predicted odor levels to those observed ranged from 1.66 to 3.12, depending on the source configuration used by the model. Predicted odors levels from the point source configuration required the smallest scaling factor (1.66) and accounted for the greatest percentage of variability in the data when compared to Nasal Ranger readings.

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INTRODUCTION

Odor nuisance complaints are a significant issue for today's livestock industry. Air pollution dispersion models can predict odor levels downwind of agricultural facilities (Janni, 1982; Carney and Dodd, 1989; Smith, 1993; Guo, et al., 2001, Curran et al., 2002) but odors are typically sensed by receptors on time intervals of less than a minute while Gaussian models are limited to dispersion calculations of no less than 10 to 15 minutes. In addition, air dispersion models were typically developed for source configurations significantly different than those of livestock facilities. Thus, there may be a need to adjust odor concentrations predicted by models to those detected by receptors in an odor plume.

The objectives of this study were to (i) establish scaling factors for the Gaussian plume air dispersion model, AERMOD, with which to predict odor dispersion from a mechanically ventilated swine finishing facility and, (ii) determine whether a point, volume, or area source configuration is the best choice for such a swine production facility. The objectives were accomplished by comparing predicted and measured odor concentrations using on-site odor emission, meteorological, and terrain data in the summer and fall of 2004 from an Iowa swine finishing facility. This was a joint research project between Iowa State University, the University of Minnesota, and the University of Nebraska.

EXPERIMENTAL DESIGN

The site was located near Story City, IA, at latitude 42° 7'51.24"N and longitude 93° 22'5.24"W, and an elevation 291 m above sea level. The data reported in this paper were from experiments conducted on June 8, 2004, between 15:15 hr and 19:20; June 9 2004, between 7:12 hr and 7:29; and November 10, 2004, between 7:15 hr and 7:59, respectively. The odor source in this study was a four-barn swine finishing facility. The buildings were surrounded by flat agricultural terrain with dimensions of about 400 m east-west and 800 m north-south. Terrain data from the U.S. Geological Survey were used to characterize the site. There were very few other odor sources within 3500 m of the site. Each of the barns was 58 m long and 12.5 m wide and was oriented east and west. A bank of tunnel fans was located on the east end of each barn, and two pit fans were located along the south side of each barn.

On each day of the experiment, four groups of receptors (sniffers) were located in the odor plume, the direction and spacing depending on wind direction. A representative layout for a group of receptors is indicated by the letters A, B, C, and D in Figure 1.

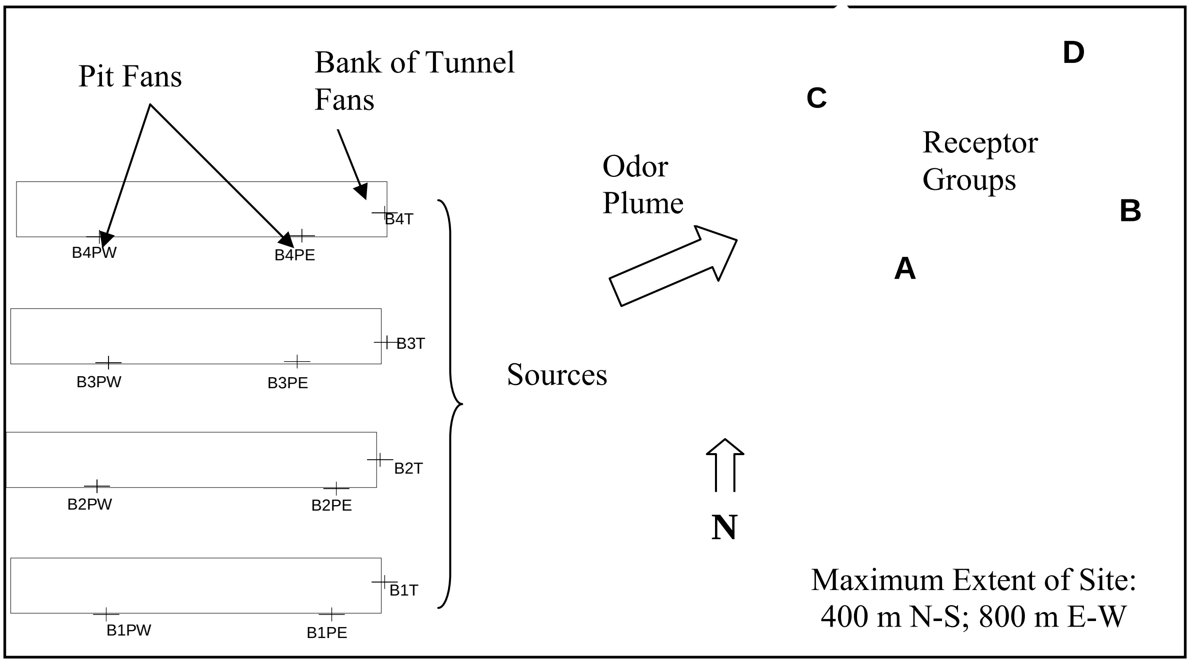

Figure 1. Layout of sources and example receptor locations.

Receptor locations, recorded via GPS equipment, ranged from 105 to 209 m from the center of the four buildings depending on the meteorological conditions at the time of the measurements. Wind bearing angles between each source and the receptors were also recorded. Odor data (from bag samples for olfactometry as well as static scale odor intensity, mask scentometry and Nasal Ranger® measurements) were obtained at each receptor location. Only the Nasal Ranger data are used in this paper. Nasal Ranger data were gathered in duplicate. The sniffers recorded Nasal Ranger readings every thirty seconds over 15-minute intervals following the prescribed dilution-to-threshold determination procedure of the Nasal Ranger.

Odor samples from the pit fans and tunnel fans were collected for the first 15-minute interval at the beginning of each one-hour sampling event and again for a 15-minute period at the end of the hour. This was done in duplicates in 10-L Tedlar sampling bags (SKC Inc. Eighty Four, PA) using a gas sampling system within a mobile emission laboratory (Heber et al., 2002). The samples were transported and analyzed for odor concentration within 24 hours using a venturi type dynamic dilution olfactometer (AC'SCENT® International Olfactometer, St. Croix Sensory, Inc. Stillwater, MN) at either the Iowa State University or University of Minnesota Olfactometry Laboratories. Emission source data also included source type, location, height, diameter, exit velocity, and temperature.

Wind speed and direction were measured using a three-cup anemometer and wind vane as well as by a high frequency sonic anemometer for the three air velocity components, average wind speed, and temperature. Relative humidity and temperature were measured using a capacitance humidity sensor and platinum resistance thermometers. Short-wave downwelling solar radiation was measured with a Licor Li-200 pyronometer and net radiation was measured using a Kipp & Zonen NR-lite net radiometer. Data from the slow-response sensors were recorded by a Campbell scientific CR10X data logger and that from sonic anemometer data were logged by a laptop computer. Cloud cover and ceiling height data for the modeling time intervals were obtained from the NCDC (2004).

Odor dispersion simulations with AERMOD enabled comparison of predicted and measured data and the impacts of assumptions regarding the following source configurations: (a) representing fans as point sources, (b) treating each building as a volume source and, (c) treating the building area as an area source.

Predicted concentrations were plotted against the measured concentrations at each receptor location. SAS Version 9.1.3 GLM software (SAS Institute Inc., 2004) was used for linear regression analysis of the data. The regression analysis was performed with the regression line being forced through the origin.

Point Sources

Ventilation air was exhausted horizontally from the buildings. AERMOD, however, only considers vertical air flow from a point source (e.g., stacks). Thus the pit and tunnel fans in the buildings were characterized with equivalent diameters and vertical exit velocities. A vertical velocity of 0.01 m/s, as recommended by EPA (2002), was used with equivalent diameters calculated using the following formula (NDEQ, 2001)

$$d_{eq} = \sqrt{v_{act}\left(d_{act}\right)^2 / 0.01}$$

where d_{eq} = equivalent diameter (m), v_{act} = actual velocity (m/s), and d_{act} = actual diameter (m).

The operating tunnel fans in each barn were combined into one equivalent fan and the two pit fans were treated as individual equivalent fans. Thus there were 12 point sources as shown in Figure 1. When the calculated equivalent diameters were greater than the building width the equivalent diameter was made equal to the building width (11.8 m). Source information for tunnel and pit fans for Barn 1 is shown in Table 1.

Table 1. Source information for Barn 1.

Date	Tunnel Fans					Pit Fans			Total Emission
	A	B	C	D	E	F	G	H	I
6/8/2004	98,189	4	68,186	58.9	11.8	7,098	2,504	11.2	70,690
6/8/2004	98,189	4	68,186	58.9	11.8	7,098	2,504	11.2	70,690
6/8/2004	98,803	4	31,105	58.9	11.8	7,162	2,061	11.2	33,166
6/8/2004	98,803	4	31,105	58.9	11.8	7,162	2,061	11.2	33,166
6/9/2004	40,244	2	22,961	37.7	10.9	7,141	1,777	11.2	24,738
6/9/2004	40,244	2	22,961	37.7	10.9	7,141	1,777	11.2	24,738
11/10/2004	14,917	1	5,184	22.9	9.4	7,165	2,977	11.2	8,161
11/10/2004	14,917	1	5,184	22.9	9.4	7,165	2,977	11.2	8,161
11/10/2004	14,917	1	6,008	22.9	9.4	7,176	6,415	11.2	12,423
11/10/2004	14,917	1	6,008	22.9	9.4	7,165	6,415	11.2	12,423

Where A = total tunnel fan airflow (m^3/hr); B = Number of operating tunnel fans; C = Total odor emission rate from tunnel fans (OU/s); D = equivalent dia. for operating tunnel fans (m) E = equivalent dia. after scaling (m); F = Volumetric air flow rate from each of the pit fans (m^3/hr); G = Total odor emission rate from each pit fan (OU/s); H = Stack equivalent dia. for each pit fan (m); Total emission rate (OU/s).

Volume and Area Sources

Total emissions (Table 1) were allocated to four volume sources, each representing a building. One challenge of volume source modeling is selection of the appropriate height. Three heights were tried: eave (2.43 m), peak (4.60 m) and mean gable (3.52 m) with little difference in outcomes. Results in this paper are from the 2.43 m eave height trials. For the area source configuration, odor emissions from each building were divided by the floor area to obtain representative areal fluxes. Model inputs for all three source configurations are shown in Table 2.

Table 2. Input parameters.

Parameter		Source Configuration		
Type of source		Point	Volume	Area
Number of sources		12	4	4
Dispersion option		No downwash	---	---
Terrain height		Flat		
Base elevation		291 m		
Stack gas exit temperature		298 K	---	---
Equivalent stack dia. (1)	Tunnel fans	11.8, 12.6, and 11.5 m	---	---
	Pit fans	11.2 m		
Stack gas exit velocity		0.01 m/s	---	---
Albedo (2)		0.2 and 0.18		
Bowen ratio (2)		0.5 and 0.7		
Surface roughness (2)		0.2 and 0.05		
Initial lateral dimension (3)		---	13.49 m	---
Initial vertical dimension (4)		---	1.13 m	---
Length of X side		---	---	58 m
Length of Y side		---	---	12.5 m
Orientation angle from N		---	---	0 deg.
Receptor height (flag pole)		1.5 m		
(1) Equivalent stack diameters for fans; (2) albedo, Bowen ratio, and surface roughness from AERMET based on cultivated land (June and November); (3) initial lateral dimension calculated based on barn length of 58 m.; (4) initial vertical dimension calculated based on barn height of 2.3 m.				

RESULTS AND DISCUSSION

The range of meteorological conditions observed during the experiments is shown in Table 3. The data obtained indicated moderately unstable to neutral conditions based on the Pasquill-Gifford (P-G) and Monin-Obukhov stability classification systems.

Table 3. Meteorological conditions.

Meteorological Conditions†	June 8	June 9	Nov 10
Cloud Cover	5	5	5
Dry Bulb Temperature (˚C)	30-33	23	5 - 7
Relative Humidity (%)	52 - 58	75 - 76	73 - 80
Pressure (mbar)	975	978	979
Wind Direction (degrees)	181 - 194	192 - 199	180 - 184
Wind Speed (m/s)	6	3	6
Ceiling Height (m)	720 - 22000	22000	22000
Precipitation (mm)	0	0	0
Radiation (W/m^2)	68 - 607	193 - 233	23 - 112
Monin-Obukhov Length	-60 to -2710	-160 to -2240	-130
P-G Stability Class	B and C	C and D	D
† 15-minute averages			

The Monin-Obukhov length is a continuous parameter for estimating atmospheric stability in contrast to the incremental P-G stability class system. It requires two quantities not routinely measured by national meteorological networks: friction velocity and sensible heat flux. The Monin-Obukhov length can be used instead of P-G stability classification in new dispersion models such AERMOD (Middleton et al., 2001; Zannetti, 2004).

Figure 2 includes the data from all ten 15-minute events on June 8, 9, and November 10, 2004 when modeled as a point source. Predicted odor concentrations were generally lower than measured odor concentrations, with predicted concentrations ranging from 1 to 45 OU/m^3 while measured concentrations ranged from 1 to 41 OU/m^3. The slope of the regression line was 0.60 (scaling factor 1.66) indicating that the model under estimated the downwind odor concentration by about 40 percent. The lack of fit of the modeled to measured data (R = 0.62), particularly for concentrations above about 20 OU/m^3, may be due to the influence of neutral atmospheric conditions on November 10 (P-G class D) not being adequately accounted for by AERMOD.

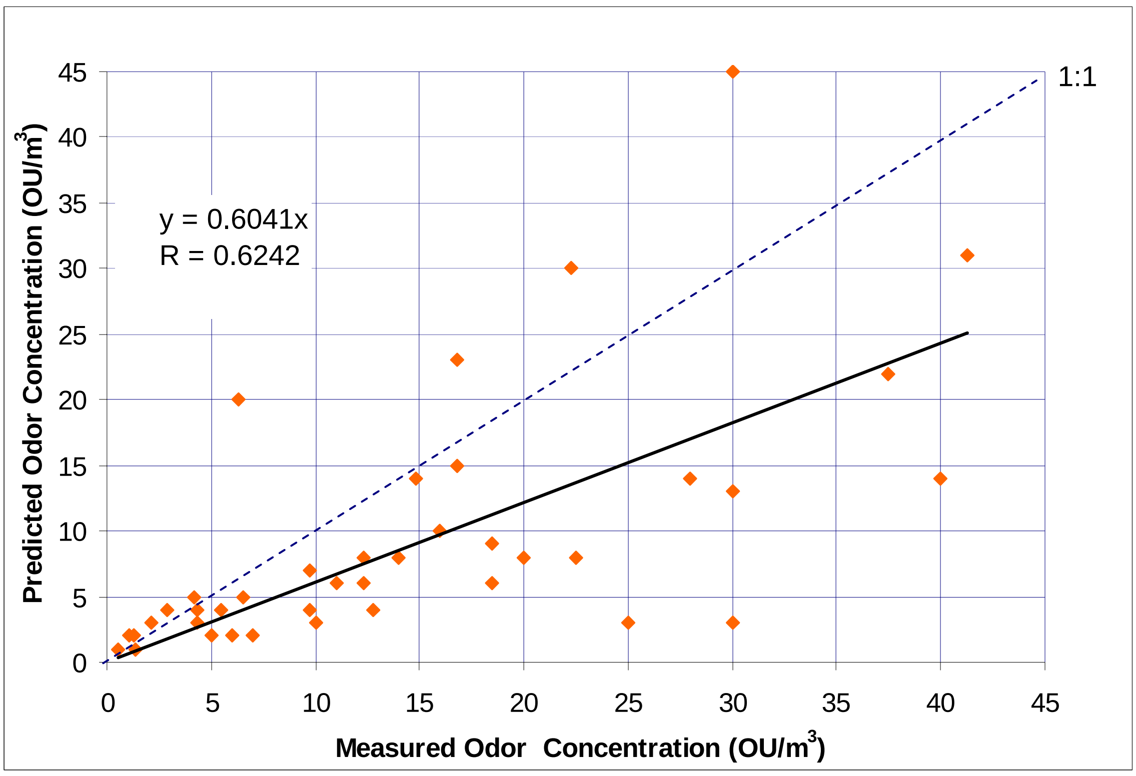

Figure 2. Point source predicted versus measured odor concentrations.

Discrepancies between predicted and measured values may also be due to assumptions about the configuration of the point sources in this study (Modi, 2006). For example, equivalent stack diameters and discharge velocities were needed because horizontal ventilation fans must be represented as equivalent vertical discharges in AERMOD. A vertical velocity of 0.01 m/s (within the range of 0.001 to 0.1 m/s suggested by the Ontario Ministry of Environment, 2003) and equivalent diameters of 11.2 to 12.6 m (needed to account for the volumetric odor discharge rate at that velocity) were assumed for the horizontal fans (Table 2). However, recent work by Niemeir (2007) indicates that these assumptions have little effect on downwind odor concentrations from a horizontally ventilated swine building. Another problematic assumption is whether downwash occurs due to building roof profiles acting effectively as stack tips. The results in Figures 2 and 3 are for point sources modeled without downwash. Recent work (Schulte, et al., 2007) indicates that using the downwash assumption reduces modeling bias and error while improving modeled and measured data correlation.

Odor emissions from the pit and tunnel fans (Table 1) were combined and modeled as a volume source in an effort to eliminate the effects of the previously discussed point source configuration (Figure 3).

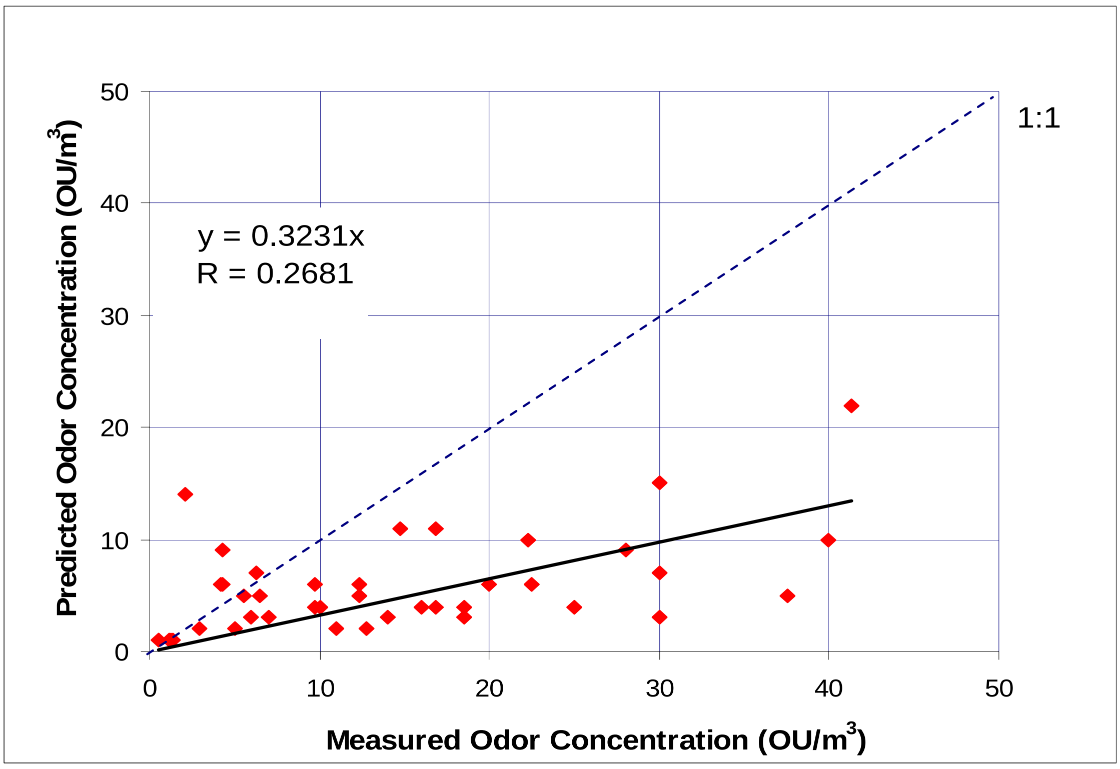

Figure 3. Predicted and measured odor concentrations for volume source.

The 0.32 slope of the regression line (scaling factor = 3.10) in Figure 3 indicates a poor relation between the two data groups. This and the lower regression coefficient (R = 0.62, Figure 2 vs. R = 0.27, Figure 3) for the volume source configuration suggests that the emission of odorous air through barn fans is more analogous to point than to volume sources.

An area source configuration was also considered, but only for the first of the 15-minute events on June 8 and 9. As with the volume source approach, AERMOD greatly under-predicted odor concentrations when configured as an area source. The results (Table 4) for the volume and areas configurations were approximately the same as one another, but quite different that those of the point source configuration.

Table 4. Predicted and measured odor concentrations for point, volume, and area source configurations.

Event and Receptor			Predicted Concentration (OU/m^3)			Measured Concentration (OU/m^3)	Pasquill Stability Class
			Point Source	Volume Source	Area Source		
Date	Time						
6/8/04	15:55-16:10	A	23	04	05	17	B or C
6/8/04	15:55-16:10	B	14	11	11	15	B or C
6/8/04	15:55-16:10	C	02	01	0	01	B or C
6/8/04	15:55-16:10	D	09	03	03	19	B or C
6/9/04	7:12- 7:27	A	20	07	04	06	C or D
6/9/04	7:12- 7:27	B	31	22	15	41	C or D
6/9/04	7:12- 7:27	C	01	01	0	01	C or D
6/9/04	7:12- 7:27	D	08	03	02	14	C or D

Spearman's rank correlation coefficient (r_s) is often used to ascertain the consistency of a model's ability to produce high results when measured results are high and conversely, to predict low results when measured results are low. An absolute value of r_s =1 is indicates perfect rank correlation, and a zero indicates a weak correlation. Depending on the assumptions discussed previously, r_s ranged from 0.34 to 0.59 indicating some, but not statistically significant ($p \leq 0.05$) rank correlation. Further analysis using this approach and the influence of outlier data points is ongoing.

A frequently used procedure, when time intervals for odor sampling by receptors are shorter than the 10 to 15 minutes considered minimum for Guassian plume dispersion modeling, involves use of scaling factors often called "peak to mean ratios" (Mahin, 1998; Pope and Diosey, 2000; Katestone Scientific, 2001; Zannetti, 2004). Peak to mean ratios are used to account for the fact that odor plumes "meander" about the centerline of the prevailing wind direction. Receptors at the plume boundaries are exposed to odor concentrations similar to that at the centerline, but this happens less frequently than at the centerline (Pope and Diosey, 2000; Katestone Scientific, 2001). Consequently, the centerline concentration of an instantaneous or short-time averaged plume is significantly higher than that in a long time-averaged (modeled) plume (Pope and Diosey, 2000). The peak to mean ratio is widely used throughout the world and is very often used to scale modeling results, even without the use of corresponding field measurements.

Scaling factors of 1.7 to 2.3 for industrial source odor models have been reported (Mahin, 1998). However, Mejer and Krause (1986) indicate that since CAFO odor plumes meander widely, especially near ground sources, and because human receptors perceive odors in very short time intervals, that CAFO scaling factors may be greater than that for industrial sources. If one assumes that Nasal Ranger® readings used in this study took approximately three seconds, and knowing that the on-site meteorological conditions were averaged over 15-minute intervals, the calculated peak to mean ratio (using a coefficient of 0.2) would be 3.14. This is approximately twice that of the point source scaling factor (1.66) and nearly the same as that for the volume source approach (3.10) found in this study. Further studies are needed to refine the relationship of calculated peak to mean ratios to those determined through on-site odor measurement and modeling. These results were based on receptor odor measurements using the Nasal Ranger and should not be used as scaling factors for predicting odor levels based on static scale intensity or bag-sample olfactometry procedures.

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