

This article was downloaded by: [Pamela Dalton]

On: 24 November 2011, At: 04:19

Publisher: Taylor & Francis

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



## Journal of the Air & Waste Management Association

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/uawm20>

### A Multi-Year Field Olfactometry Study Near a Concentrated Animal Feeding Operation

Pamela Dalton<sup>a</sup>, Edward A. Caraway<sup>b</sup>, Herman Gibb<sup>d c</sup> & Keri Fulcher<sup>d</sup>

<sup>a</sup> Monell Chemical Senses Center, Philadelphia, Pennsylvania, USA

<sup>b</sup> West Texas A&M University, Canyon, Texas, USA

<sup>c</sup> George Washington University School of Public Health, Washington, DC, USA

<sup>d</sup> Tetra Tech Sciences, Arlington, Virginia, USA

Available online: 23 Nov 2011

**To cite this article:** Pamela Dalton, Edward A. Caraway, Herman Gibb & Keri Fulcher (2011): A Multi-Year Field Olfactometry Study Near a Concentrated Animal Feeding Operation, Journal of the Air & Waste Management Association, 61:12, 1398-1408

**To link to this article:** <http://dx.doi.org/10.1080/10473289.2011.624256>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.tandfonline.com/page/terms-and-conditions>

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

# A Multi-Year Field Olfactometry Study Near a Concentrated Animal Feeding Operation

**Pamela Dalton**

*Monell Chemical Senses Center, Philadelphia, Pennsylvania, USA*

**Edward A. Caraway**

*West Texas A&M University, Canyon, Texas, USA*

**Herman Gibb**

*Tetra Tech Sciences, Arlington, Virginia, USA; and George Washington University School of Public Health, Washington, DC, USA*

**Keri Fulcher**

*Tetra Tech Sciences, Arlington, Virginia, USA*

## ABSTRACT

This study developed and tested a protocol for monitoring odors near a Concentrated Animal Feeding Operation (CAFO). The Nasal Ranger, a portable field olfactometry instrument, was used by a panel of trained individuals to conduct the monitoring near a swine CAFO. Monitors were selected based on olfactory sensitivity, scheduling availability, and lack of association with the CAFO or residential neighbors of the CAFO. Monitors were trained to use the Nasal Ranger, collect and record weather data, and characterize any odors detected. Data were collected over a 3-year period (2007-2009) for approximately 9 months each year. The data recorded included odor intensity, a description of the odor, date and time of the reading, and weather conditions.

Of more than 50,000 readings, forty-one (0.1%) odor readings had a dilution to threshold ratio (D/T) of  $\geq 7:1$  and were attributed to hog manure. The frequency of odor readings attributed to hog manure with  $D/T \geq 7:1$  was found to negatively correlate with log wind speed and positively correlate with wind from the direction of the farm. Other meteorological variables (temperature, precipitation, cloud cover) and time of day did not influence the frequency.

## INTRODUCTION

Odors associated with livestock production are often the primary trigger for complaints made by individuals living in nearby communities. In particular, complaints about odorous emissions from CAFOs are a focal point, likely due to both the perceived and actual potential for odors to be

emitted from facilities housing large numbers of animals. For this reason, the monitoring of animal odor emissions has become an urgent priority for the livestock industry and the neighboring communities. Unfortunately, in many instances, quantifying and objectively determining the odor impact of livestock operations on nearby communities has posed challenges.

Odor nuisance is generally defined by the FIDO factors: frequency, intensity, duration, and offensiveness, where frequency refers to the number of times an odor occurs, intensity refers to the strength of an odor, duration refers to the period of time during which an odor is detected, and offensiveness refers to the unpleasantness or character of the odor.<sup>1-3</sup> Offensiveness or the hedonic tone of an odor is a highly subjective attribute and can vary widely across individuals and even within the same individual over time. The intensity, frequency, and duration of an odor, however, can be objectively determined. Thus these are the factors used to determine violations in states in the United States, which regulate nuisance odors and, along with descriptors of the odor, formed the primary data of interest in the current study.

Assessment of ambient odors presents difficulties due to the low concentrations of odor commonly experienced and the rapidly fluctuating conditions that occur over time. Researchers have suggested that CAFOs generate between 100 and 330 different volatile and semivolatile organic compounds (sVOCs) and volatile fatty acids (VFAs), depending on species of animal and management practices.<sup>4-6</sup> Some of these constituents have the potential to contribute to odor impact more than others, and many are difficult, if not impossible, to quantify in real time. Instruments can provide information on individual constituents (e.g., ammonia and H<sub>2</sub>S) but not on the odor per se. In contrast, the human nose integrates the odors of the various constituents allowing hundreds of compounds from a single source to be experienced as a unitary odor. Thus, the most sensitive and reliable way to obtain data on the frequency, intensity, duration, and quality of an odor is

## IMPLICATIONS

The use of a portable field olfactometry instrument can provide an assessment of the intensity, frequency and duration of odor in real time. Along with descriptors of the odors being detected, such data can provide a basis for the evaluation of odor complaints.

to use the human nose as the detection instrument, a well-established method known as olfactometry.

Laboratory-based olfactometry, in which an air sample collected at or near the source is brought into the laboratory and successively diluted in an olfactometer until the 'detection threshold' is obtained, has generally been the gold standard for measuring odor concentrations.<sup>7,8</sup> In those states in the United States that have a "nuisance odor rule," laboratory olfactometry performed by a panel of trained individuals is used to confirm readings taken in the field by human observers. In the ambient atmosphere, though, odor concentrations can be quite low and extremely variable within a short period of time. Ensuring the collection of air samples that are sufficiently representative of the ambient conditions can be difficult. In addition, laboratory olfactometry is typically more reliable at assessing odors at higher concentrations than at the lower concentrations encountered downwind from an odor source. The adsorption of malodorous compounds to the Tedlar bags used to collect the samples, or to surfaces within the olfactometer, may explain why quantification of odor measured in the field is substantially higher than odor quantified in the laboratory.<sup>6</sup>

Field olfactometry represents a major advance in the ability to objectively quantify odor intensity and impact in real time. One instrument developed to perform human odor detection in field conditions is the Nasal Ranger.<sup>9</sup> The Nasal Ranger is a portable olfactometry instrument capable of diluting inhaled ambient air at six dilution levels for real-time assessment of odor intensity and impact. The dilution to threshold (D/T) ratio obtained from such a device has been used as the basis for developing a nuisance odor rule. Odors of dilution to threshold ratios  $>7:1$  have been described as likely "to cause complaints."<sup>10</sup> A dilution ratio of 7:1 or greater, obtained in two separate trials not less than 15 min apart within the period of 1 hr, constitutes a nuisance odor violation for certain facilities in Missouri.<sup>11</sup> The Nasal Ranger has been successfully used for quantifying the intensity of odors in numerous industrial and

agricultural operations and due to its reliability and portability was the instrument of choice for this study.<sup>12-15</sup>

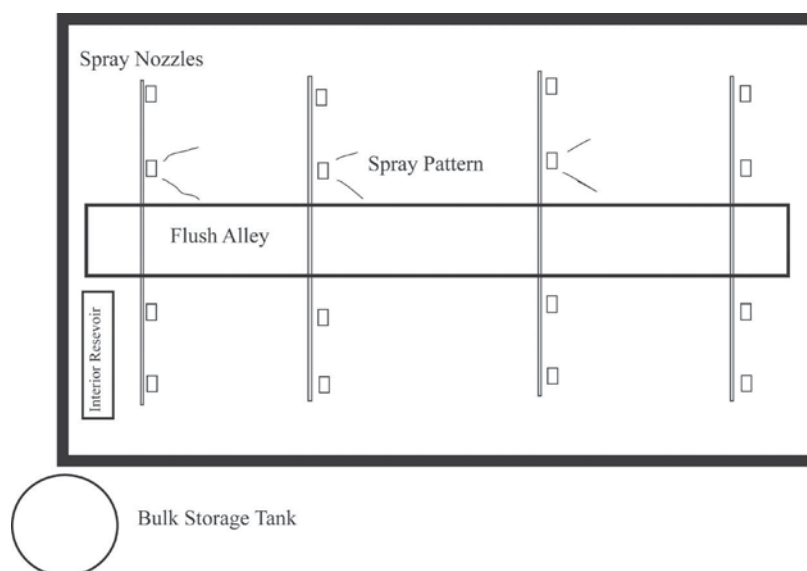
However, mounting a credible odor monitoring program involves more than just the selection of a suitable field olfactometer. As described in McGinley and McGinley,<sup>16</sup> there are four components to an odor monitoring program: qualified monitors, objective observational methods, standard monitoring practices, and standard data collection and report forms. Following these guidelines, the goals developed for the current study were (1) to evaluate the magnitude and frequency of odors downwind from a swine CAFO; and (2) to determine whether meteorological variables and time of day have an impact on the frequency of odors.

## METHODS

The agricultural operation selected for study was a Class 1B swine farm, located in northwest Missouri. A Class 1B Facility is classified as a facility housing 7500-17,499 swine over 30 kg or 30,000-69,999 under 30 kg.<sup>17,18</sup> There were five barns located on the property. Average animal numbers for each barn are provided in Table 1. Waste (urine and feces) from the barns was periodically flushed using recycled lagoon water and discharged into a storage lagoon using a system depicted in Figure 1. Spray nozzles were used to flush

**Table 1.** Average number of swine by category (farrowing, nursery, females, boars) and barn for the period January through July 2009.

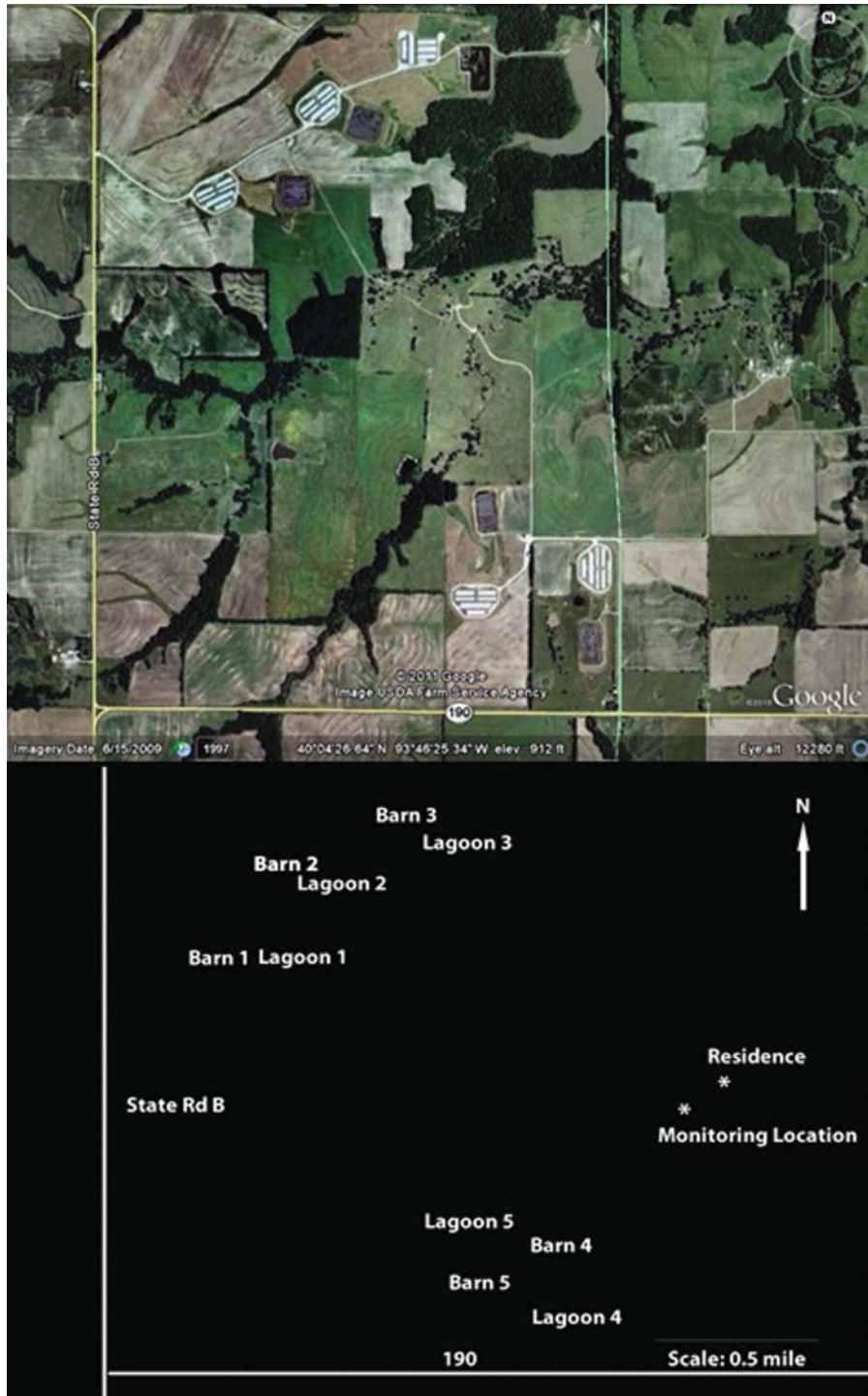
	Farrowing	Nursery	Female	Boar
Barn 1	3792	4700	2346	9
Barn 2	3790	5350	2380	13
Barn 3	3930	4361	2300	14
Barn 4	3996	4465	2351	15
Barn 5	4235	4297	2620	10



**Figure 1.** Schematic of barn. This scheme depicts the flushing design of a typical barn on this farm. Waste is flushed three times daily using recycled lagoon water.

the waste material three times daily to the flush alley. A reservoir and bulk storage tank contained water used for the flushing. The flush alley emptied to a pipe that carried the manure to a lagoon that was fitted with a permeable cover made of nonwoven polypropylene geotextile fabric.<sup>19</sup> The monitoring site chosen was located near the eastern

most property line of the swine farm (Figure 2). The swine farm borders the property of a nearby residence. Barn 4 and Lagoon 5 are approximately 1100 and 1300 m, respectively, from the residence itself (Table 2). The Missouri Department of Natural Resources (DNR) states that a minimum buffer distance of 600 m is required between the nearest

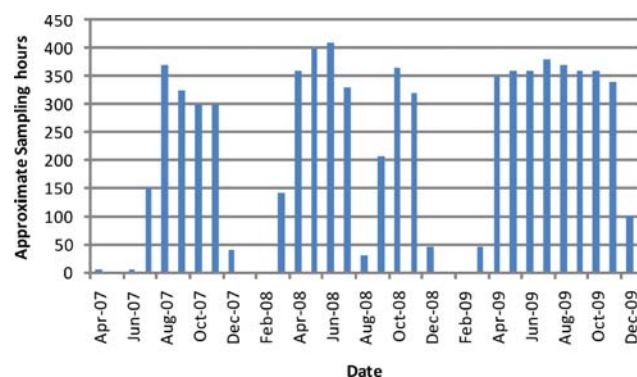


**Figure 2.** Top panel is a satellite image of the farm courtesy of Google Earth. Bottom panel is a schematic overlay for the image showing the approximate locations of barns and lagoons and the monitoring site relative to the farm. Barns and lagoons were labeled arbitrarily for reporting of distance to the monitoring site.

Downloaded by [Pamela Dalton] at 04:19 24 November 2011

**Table 2.** Distances in meters from the monitoring location to the various barns and lagoons situated on the CAFO property.

Location	Distance from Monitoring Location
Barn 1	2575 m
Lagoon 1	2253 m
Barn 2	2349 m
Lagoon 2	2140 m
Barn 3	2124 m
Lagoon 3	1960 m
Lagoon 4	1319 m
Barn 4	1046 m
Barn 5	1529 m
Lagoon 5	1270 m

**Figure 3.** Approximate sampling time at the monitoring site across the 3 years in which data were collected.

confinement building or waste holding basin and any public building or occupied residence.<sup>17,18</sup> The prevailing wind for the site is south-southwest.

Data were collected over a 3-year period, approximately 9 months each year. Nasal Ranger data were collected at the monitoring site every 7 min, 12 hr per day, for roughly 7100 hr of sample time (Figure 3). For each Nasal Ranger reading, the following were also reported: wind speed; wind direction; weather condition (sunny, hazy, partly cloudy, mostly cloudy, overcast); precipitation (none, fog, snow, rain, sleet); temperature; and time of day.

### Monitors

Monitors (individuals doing the odor detection) were recruited through advertisements placed in local papers and through a local employment agency. Selection of monitors was contingent on appropriate levels of olfactory sensitivity (determined as described below), ability to comply with the scheduling needs, and lack of association (their own or family members) with the facility or with any of the residential neighbors of the facility. All were screened for olfactory sensitivity to *n*-butanol "Sniffin" Sticks (Burghart, Germany) provided by St. Croix Sensory. Thresholds between dilution steps 4 (strongest) and 13 (weakest) were required for inclusion; those scoring higher or lower than those dilutions were not invited to join the

**Table 3.** Gender, age, and smoking status of monitors by year.

Year	2007	2008	2009
Number of females	7	4	4
Number of males	18	14	8
Mean age (range) of females	37 (21–51)	37 (22–52)	21(18–26)
Mean age (range) of males	28 (19–60)	33 (20–61)	29 (22–62)
Smokers female	0	0	0
Smokers male	10	6	4

panel (the group of trained monitors). The gender, age, and smoking status of the monitors were recorded (Table 3). Per guidelines established for laboratory and field olfactometry,<sup>20,21</sup> smokers were included as odor monitors if they met the sensitivity criteria, because no statistically significant differences in odor assessment ability have been found between smokers and nonsmokers. Olfactory sensitivity was retested at periodic intervals throughout the monitoring season (~4–6 weeks), as well as after an individual reported the occurrence of a cold, allergy, or nasal congestion. All were free of chronic respiratory conditions, allergies, or cold symptoms at the time of hiring and at any time that they monitored.

Monitors underwent a 1-day training session conducted by either personnel from St. Croix Sensory or by certified Nasal Ranger instructors. The training involved descriptions of basic nasal anatomy, odor chemistry, odor observation techniques, meteorology, standard field procedures, and recording formats. Practice and feedback on performance with the Nasal Ranger instrument was also included in the training. It was also necessary to ensure that monitors had sufficient familiarity with the perceptual quality of the various agricultural odors so that they could accurately characterize them using the descriptors on the odor wheel (Figure 4). This odor wheel was modified from the standard one developed by St. Croix Sensory to include additional descriptors necessary to distinguish varying sources of manure (i.e., hog vs. cow vs. other) as well as manure used in land application, which was characterized as hog and noted as land application on the data sheet if the monitors observed land application taking place in the vicinity. To familiarize the monitors with hog odor, they were brought onto the facility/property where, at varying distances, they experienced the odors emanating downwind from a barn containing live animals and from a waste lagoon.

Monitors were scheduled to work in 4-hr shifts, sometimes two per day, but never without a minimum 4-hr break between shifts. On the day of their odor monitoring session, monitors were instructed to refrain from using strongly fragranced soaps or shampoos, perfume, aftershave, cologne, or scented powder, wearing strongly scented clothing (i.e., leather), eating strongly flavored foods, or drinking alcohol.<sup>20–23</sup> For 1 hr prior to the session as well as throughout the session, they were also to refrain from smoking or chewing tobacco, eating, drinking any beverage except water, and chewing gum or mints, which was more restrictive than the 30-minute abstention guideline established by the European Central Commission.<sup>21</sup> Monitors were provided with scent-free sunscreen and

insect repellent to use as needed. No other products were permitted before or during the monitoring session.

### Nasal Ranger Equipment

All Nasal Ranger olfactometers used in this study were provided by the manufacturer, St. Croix Sensory (Stillwater, MN). They were calibrated by the manufacturer at the beginning of the monitoring season and returned for calibration checks at the end of the season. All units were inspected and found to be calibrated and operating within specifications at the time of return. During the monitoring season, routine maintenance of the equipment was the responsibility of the project managers, who inspected the equipment regularly and changed the air filters and the O-rings according to the manufacturer's recommended schedule.

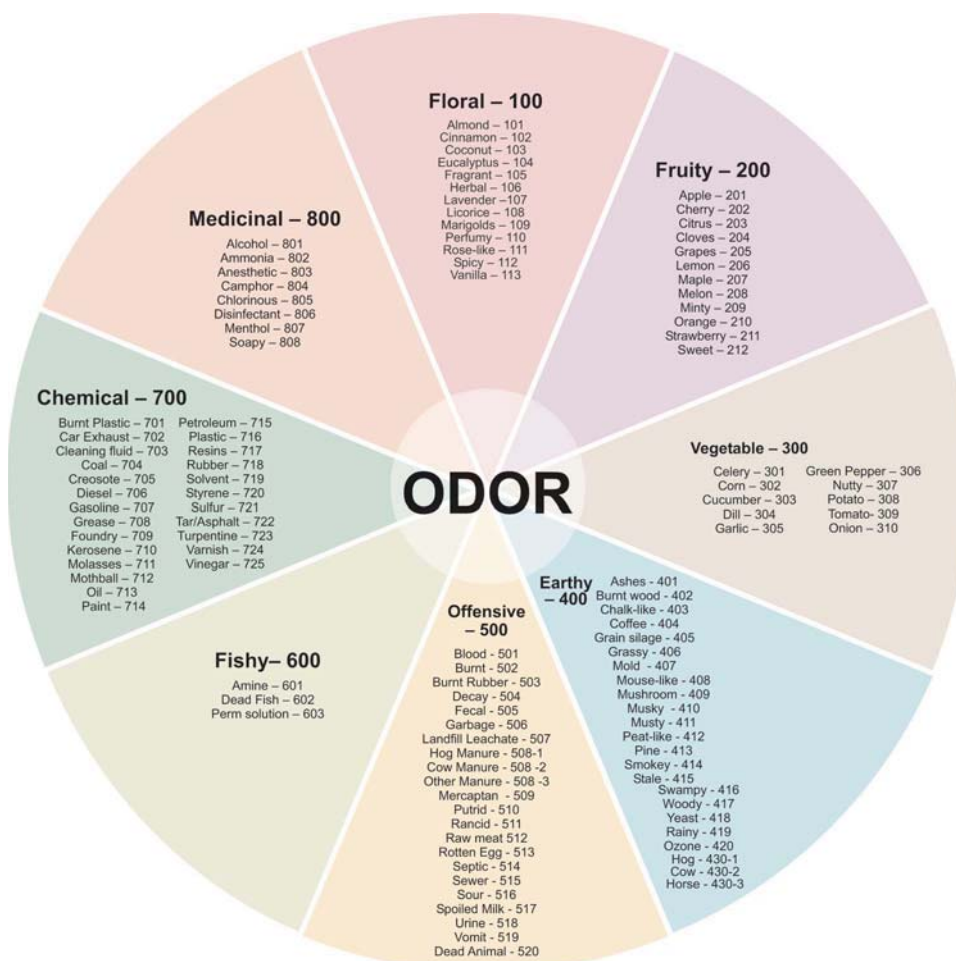
### Data Collection

Odor data sheets were completed according to the monitoring protocol, as part of the comprehensive monitoring program.<sup>16</sup> The odor monitoring protocol consisted of recordings of (1) date and time of the reading; (2) odor intensity (dilutions to threshold) using the Nasal Ranger; (3) odor descriptors (using a modification of the standard odor descriptor wheel for environmental odors, shown in Figure 4); and (4) weather conditions, including temperature

and wind speed and direction, and atmospheric conditions (e.g., raining, cloudy, sunny). Temperature, wind speed, and direction were measured with the use of a SkyWatch portable weather station (JDC Electronic, Yverdon-les-Bains, Switzerland). Monitoring began at 7:00 a.m. and continued until 7:00 p.m., 7 days per week throughout the monitoring season. Except on rare occasions when travel difficulties or illness precluded a monitor from arriving at the start of their shift, two monitors were monitoring at all times. Monitors sat outside unless weather conditions dictated otherwise (they were permitted to sit in their car between readings when the temperature was below 0 °C, or when precipitation contraindicated use of the Nasal Ranger).<sup>24</sup>

Each of the two monitors at the site was instructed to take a Nasal Ranger reading at 15-minute intervals, but they did so in alternating fashion. So, if monitor A took a reading at 7:00 a.m., monitor B would take a reading at 7:07 a.m. If, however, an odor was detected at anytime between the scheduled readings, the monitors were instructed to make an additional reading to capture the intensity and quality of that odor.

The Nasal Ranger readings were taken by having the monitor stand with their shoulder to the wind. They placed the Nasal Ranger instrument over their nose, turned the dial to the Blank position, and breathed normally through the



**Figure 4.** The odor wheel used by monitors to identify the quality or source of the odors detected. Monitors recorded the number associated with the odor descriptor on their data sheet and added any comments necessary to identify the odor source (e.g., land application).

mask for 1 minute. As all ambient air was drawn through a charcoal filter with the dial in this position, this allowed the monitors to “zero” their nose prior to taking a reading. They then turned the dial to the starting dilution ratio used (initially 60 D/T but later modified to be 15 D/T, as explained below) and inhaled twice at the target inhalation rate (16–20 liters per minute as indicated by green LED lights). After two inhalations they turned the dial to the next Blank position, resumed normal breathing, and judged whether they had smelled an odor at that dilution. If the monitor did experience an odor, they would then indicate on the data sheet that the D/T was equal to or greater than that dilution ratio. If they did not smell an odor at that dilution, they turned the dial to the next lower dilution ratio and inhaled twice. This process was repeated until they either did or did not smell an odor at the lowest dilution ratio.<sup>16</sup>

On the rare occasions when the Nasal Ranger could not be used due to weather conditions (temperatures below 0 °C or rain), monitors were instructed to record any odor detected, apply one of the descriptor codes, if possible, but to indicate that the reading was taken without the use of the Nasal Ranger.

During the first monitoring year, it became apparent that the vast majority of odors in this field setting did not exceed a 15 D/T ratio. Therefore, monitors were instructed to begin their readings at 15 D/T to minimize the time necessary to take a reading. If, on rare occasion, an odor was detected at that dilution, they would subsequently move two dilution steps higher (60 D/T) on the next trial and proceed downward from there. At the end of each shift, the monitors would sign their data collection sheet and turn the equipment over to the next scheduled monitors.

### Data Analysis

Data from the individual reporting sheets were entered into an Excel spreadsheet. Analysis was done using SAS Version 9.1. Frequency tables of meteorological conditions were

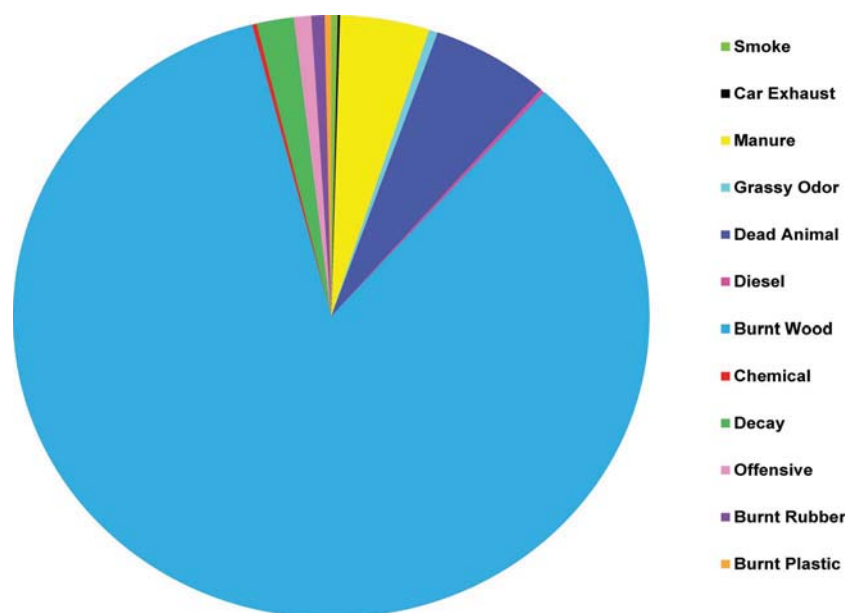
prepared using PROC FREQ for categorical variables and PROC UNIVARIATE for continuous variables. Regression analyses of odor events (dependent variable) and meteorological data (independent variables) were done using SAS Version 9.1 PROC LOGISTIC for REGRESSION. These analyses included the effect of different meteorological variables on: odor with D/T of  $\geq 7:1$  versus no odor and hog odor of D/T  $\geq 7:1$  versus no odor. Variables with kurtosis and/or skewness  $>3$  or  $<3$  were transformed (e.g., log transformation). Wind direction was treated as a categorical variable. Wind considered to be blowing from the farm (southwest [SW], south-southwest [SSW], and west-southwest [WSW]) = 1; all other wind directions = 0. Log windspeed and temperature were modeled as continuous variables. Reference variables for precipitation and weather were selected by the model.

Final models were produced using backward selection methods. Variables were removed if their *P* value was above the significant level of 0.05. Models were evaluated for goodness of fit using the Hosmer and Lemeshow test. R-square values were examined using the RSQUARE option. These factors were also considered when choosing the final model.

### RESULTS

There were 50,160 odor readings between April 2007 and December 2009; 2595 of these were odor from manure. There were 189 instances where monitors identified the odor from manure as “cow,” which could be attributed to grazing livestock at nearby residences; the remainder of odor reports for manure were attributed to hog manure ( $n = 2406$ ). Nine hundred and one odor readings were D/T  $\geq 7:1$ ; 41 of these were hog odor. The distribution of odors with D/T  $\geq 7:1$  by type of odor is described in Figure 5.

There was only one odor reading of D/T  $\geq 7:1$  in 2007; it was not from hog manure. There were 93 and 807 odor events of D/T  $\geq 7:1$  in 2008 and 2009, respectively. The largest number of observations of odors of D/T  $\geq 7:1$  in 2008 were attributed to a dead deer adjacent to the sampling



**Figure 5.** Distribution of odors of D/T  $\geq 7:1$  (data from 2007, 2008, and 2009 combined).

**Table 4.** Nasal Ranger readings D/T 7:1 and above for 2008 and 2009.

Nasal Ranger Reading	2008	2009
D/T 7:1	12	18
D/T 15:1	5	2
D/T 30:1	1	2
D/T 60:1	1	0
Total	19	22

station; the largest number during 2009 were attributed to smoke from a wood burning stove near the sampling location. There were 19 and 22 elevated ( $\geq 7$  D/T) readings attributed to hog manure in 2008 and 2009, respectively (Table 4). Of the 50,160 readings, 1326 occurred without the use of the Nasal Ranger (i.e., no D/T data) because of heavy rain or temperatures below 0 °C. None of the 1326 odor readings that occurred without the use of the Nasal Ranger recorded odor of any type.

Table 5 depicts 16 events where the odor was detected at D/T  $\geq 7:1$  for more than two consecutive readings taken at 7.5-minute intervals. Seven of those events were characterized as hog odor or land application. The land application descriptor was included in the total hog odor time. The remainder of events was attributed to dead animal and smoke. The duration of odors experienced from wood burning and the dead animal carcass exceeded that of hog odor (38 hr, 35 min for wood burning and dead animal carcass vs. 9 hr, 25 min for hog odor).

The 3 years of data of odor of D/T of 7:1 are graphed by month in Figure 6. Season and month did not appear to have an effect on odor from hog manure of D/T  $\geq 7:1$ . There is a suggestion that odor events of D/T  $\geq 7:1$  were more common in the autumn months, but this was an episodic

occurrence resulting from odors from a wood-burning stove in 2009. When odors of D/T  $\geq 7:1$  were analyzed by month for 2008, there was no evidence of an effect of season or month (there was only one odor of D/T  $\geq 7:1$  in 2007).

There were 6904 observations in 2007; only 45 of these recorded meteorological data. The vast majority of the 43,256 observations recorded in 2008 and 2009 included meteorological data. The frequency of the different meteorological variables is reported in Table 6. The reference variables (categorical variable with lowest frequency of odor events) for weather condition and precipitation were determined to be sunny and snow, respectively.

The regression analysis of odors from any source of D/T  $\geq 7:1$  found that log wind speed, temperature, wind direction, and time of day were negatively correlated; none of the meteorological variables were positively correlated.

The best fitting model for all those evaluated was for odor from hog manure with odor strength of D/T  $\geq 7:1$  (Table 7) in which wind direction from the farm was positively correlated and log wind speed was negatively correlated.

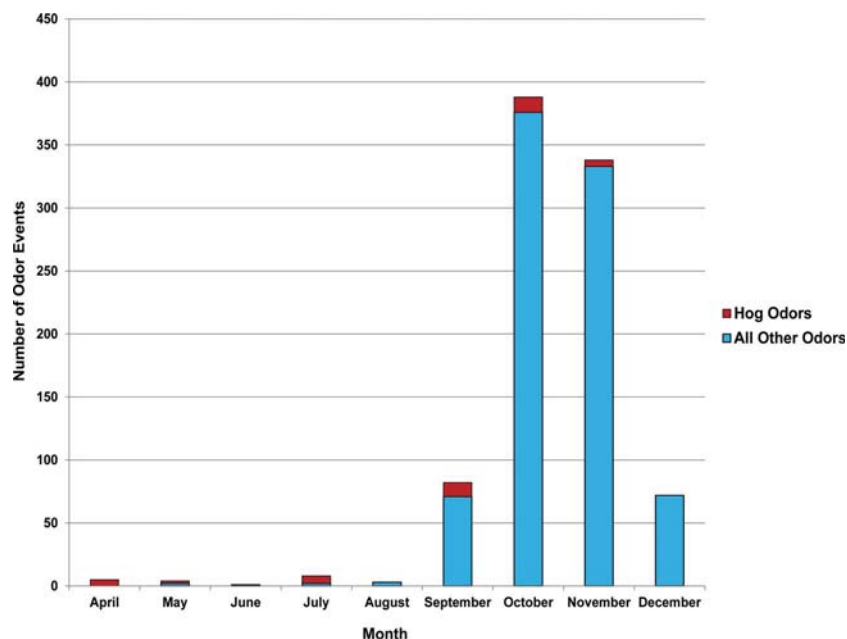
## DISCUSSION

Instrumental monitoring of selected constituents of an odor plume (i.e., ammonia or hydrogen sulfide) is a well-standardized tool that is relatively easy and inexpensive to implement. By itself, this method is most usefully applied when investigating whether levels of any particular agent exceed those known to produce health effects. In those circumstances, untrained individuals often overestimate the health hazard of an odor based solely on intensity, as most fail to recognize that many odorous compounds can be detected at minute (parts per billion or even parts per trillion) concentrations, often orders of magnitude below those concentrations capable of harming human health.<sup>25-27</sup>

**Table 5.** Events during the 2008–2009 data collection period, where the wind was from westerly directions and there were more than two consecutive field D/T readings of  $\geq 7:1$ .

Date	Season	Duration	Descriptor	Monitor Comments
April 26, 2008	Spring 2008	40 min	508	Hog
July 21, 2008	Summer 2008	2 hr	508	Hog
September 17, 2008	Fall 2008	5 hr 45 min	504	Dead animal (deer), decay
September 19, 2008	Fall 2008	2 hr 20 min	504	Dead animal (deer)
May 29, 2009	Spring 2009	1 hr 15 min	700	Land application: hog odor
September 25, 2009	Fall 2009	1 hr 15 min	508	Hog
October 9, 2009	Fall 2009	4 hr	402	Wood burning furnace north of site
October 10, 2009	Fall 2009	4 hr	402	Wood burning furnace north of site
October 24, 2009	Fall 2009	2 hr	500, 508	Odor not identifiable, hog
October 25, 2009	Fall 2009	1 hr	508	Hog
October 26, 2009	Fall 2009	10 hr	402	Wood burning furnace north of site
November 7, 2009	Winter 2009	30 min	508	Hog
November 14, 2009	Winter 2009	1 hr 30 min	402	Wood burning furnace north of site
November 17, 2009	Winter 2009	6 hr	402	Wood burning furnace north of site
November 20, 2009	Winter 2009	45 min	508	Hog
November 29, 2009	Winter 2009	5 hr	402	Wood burning furnace north of site
Total manure/hog		9 hr 25 min (1 hr 15 min were attributed to land application)		
Total wood burning		30 hr 30 min		
Total dead animal (deer)		8 hr 5 min		
Total		48 hr		

Note: Duration was calculated as the amount of time (in minutes/hours) between the first elevated odor reading attributed to that source and the next "no" or non-elevated ( $<7:1$  D/T) odor reading.



**Figure 6.** Odor events of  $D/T \geq 7:1$  by month by hog odor and all other odors (2007, 2008, and 2009 combined).

Simply measuring one or more individual constituents that may be contributing to the perception of an odor can lead to an incomplete picture of the odor impact to a human observer, as odor plumes from CAFOs contain hundreds of odorous compounds.<sup>4-6</sup> Unlike analytical instrumentation, which is capable of separately analyzing emission constituents, the human nose integrates the odors of the various constituents, combining the myriad compounds from an odor source into a unitary odor percept, which can then be quantified as to intensity and identified based on perceptual quality. This method is the most ecologically relevant for understanding the odor impact on a community surrounding an agricultural operation or any odor source.

Field olfactometry, although expensive and labor-intensive, has decided advantages over measuring individual constituents (e.g., hydrogen sulfide, ammonia) and laboratory-based olfactometry. To gain experience with the protocol, it was tested throughout the daytime hours over a multiyear period. To the best of our knowledge, an odor monitoring study of the magnitude of the current study has never been conducted.

The use of trained monitors to serve as “surrogates” for individuals in the community provided an objective method of evaluating whether odors emanating from agricultural facilities could be deemed “nuisance” odors by the neighboring community. The opportunity to collect odor data from a well-characterized stationary source across multiple years, different seasonal conditions, different meteorological conditions, and times of the day helped to evaluate factors that may contribute to off-site odor migrations. Other odors that could arise in an agricultural setting and be misattributed to the facility by concerned residents were also identified.

Many factors have been reported to affect the degree to which odors from a CAFO will impact a community, such as distance from receiver to the barns and lagoons, and

meteorological conditions, including ambient temperature, wind speed and atmospheric stability.<sup>14,15,28,29</sup> The evidence, although limited, suggested no evidence of a seasonal effect for hog odor. There was a suggestion of a higher frequency of DT readings  $\geq 7$  in the autumn for odors other than hog odor, but these readings could be considered episodic.

In particular, stable atmospheric weather conditions, which are typically observed from the late afternoon through to early morning, are conducive to the horizontal travel of odor and allow odors to be detected at greater distances from the source. Consistent with this phenomenon, studies conducted by Guo et al.,<sup>30,31</sup> which used resident observers to document odor frequencies in the vicinity of a swine farm over an 11-month period, observed that peak hours for odor detection were early morning (6:00 a.m. to 7:00 a.m.) and late afternoon (4:00 p.m. to 5:00 p.m.), accounting for 10.4% and 9.8% of the annual odor events, respectively. Daytime hours between 12:00 p.m. and 2:00 p.m. accounted for only 5.4% of odor events. Similarly, Wing et al.<sup>29</sup> found that individuals living less than 2400 m from a CAFO reported the frequency of elevated odors to be highest in the morning and evening hours, with fewer at the midday period. In contrast, Pan et al.,<sup>28</sup> using trained panelists employing a Nasal Ranger to evaluate odors from dairy farms, reported a higher frequency of elevated odors occurring at midday, which they attributed to midday increases in ambient temperature. That study, however, monitored at relatively short distances from the odor source, whereas in our study the monitoring location was 1046 m from the nearest barn and 1270 m from the nearest lagoon. Sheffield et al.<sup>12</sup> found that the frequency of detections of elevated odors decreased dramatically when the evaluators moved from just adjacent to the odor source to a distance of 200 m. The vertical mixing and rapid dispersion of odor that occurs

**Table 6.** Frequency of nasal ranger readings by meteorological variables.

Weather Condition				
Weather Condition (N = 43,267)	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Hazy	124	0.29	124	0.29
Mostly Cloudy	19,423	44.89	19,547	45.18
Overcast	11,953	27.63	31,500	72.80
Partly Cloudy	808	1.87	32,308	74.67
Sunny	10,959	25.33	43,267	100.00

Precipitation				
Precipitation (N = 43,278)	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Fog	204	0.47	204	0.47
None	39,830	92.03	40,034	92.50
Rain	2,981	6.89	43,015	99.39
Sleet	30	0.07	43,045	99.46
Snow	233	0.54	43,278	100.00

Wind Direction				
Wind Direction (N = 38,113)	Frequency	Percent	Cumulative Frequency	Cumulative Percent
E	3150	8.26	3,150	8.26
ENE	42	0.11	3,192	8.38
ESE	36	0.09	3,228	8.47
N	5124	13.44	8,352	21.91
NE	1988	5.22	10,340	27.13
NNE	25	0.07	10,365	27.20
NNW	57	0.15	10,422	27.35
NW	6281	16.48	16,703	43.82
S	7325	19.22	24,028	63.04
SE	6050	15.87	30,078	78.92
SSE	65	0.17	30,143	79.09
SSW	90	0.24	30,233	79.32
SW	5079	13.33	35,312	92.65
W	2715	7.12	38,027	99.77
WNW	68	0.18	38,095	99.95
WSW	18	0.05	38,113	100.00

N	Mean	SD	Minimum	Maximum	Median	Range
43,156	5.656	5.746	0	86	4	86
43,156	1.485	0.986	0	4.466	1.485	4.466
50,151	12.654	3.575	0	20	13	20
43,264	17.028		12.785	-17.778	40	57.778

during warm, sunny weather is also compatible with our data showing that temperature was negatively correlated with odor events when considered with other variables in a multiple regression.

Although we did not measure all of the factors necessary to calculate atmospheric stability, we did observe that wind speed was negatively correlated with the detection of elevated odors, including hog odors, consistent with previous reports.<sup>31</sup> However, despite the fact that we regularly monitored during late afternoon into evening (4:00 p.m. to

7:00 p.m.) and again in the early morning (7:00 a.m. to 8:00 a.m.), time of day had little if any effect in the various regression analyses that were conducted on the detection of elevated odors. The discrepancy between our data and those studies conducted with resident observers could arise because residents are not always present during daytime hours, whereas our trained monitors were on site from 7:00 a.m. to 7:00 p.m. daily.

The use of resident observers to monitor odor events, although practical and inexpensive, has additional

**Table 7.** Variables demonstrating significant correlation with odor from hog manure of D/T  $\geq$  7:1.

Parameter	Estimate	Wald Chi-Square	P Value
Intercept	-5.4694	536.0289	<0.0001
Wind = SW, SSW, WSW	1.4515	77.1734	<0.0001
Log windspeed	-0.6597	15.8377	<0.0001

drawbacks, which our study did not. These factors included, but were not limited to, (1) dependence on the potentially sporadic monitoring schedule of the residents; (2) lack of quality control for the data (i.e., no sensitivity calibration, no objective odor detection measurement); and (3) the possibility of resident bias for or against the livestock operation.

The odor impact to neighboring communities from CAFOs can also occur from land application agreements between the CAFO and neighboring farms. Over the 2-year period that was analyzed in this study, land application took place in the immediate vicinity of the monitors three times; however, only in one instance did this result in elevated odors at the monitoring location and this impact lasted only for 1 hr and 15 min.

In this analysis, we regarded any odors detected at a dilution to threshold ratio of 7:1 as elevated, consistent with previous investigators and the threshold for the nuisance odor rule in Missouri. In practice, however, other investigators in this field have found that odors detected at dilution ratios less than 15:1 do not reach an unacceptable nuisance odor for the majority of individuals in a community.<sup>12</sup> In the present study, consideration of only those readings where the D/T was  $\geq$  15:1 reduces the percentage of all elevated readings from 0.2% to 0.1% of the total and reduces those attributed to hog/manure from 0.1% to 0.05%.

Given that many CAFOs, including this one, are sited in a rural area where other agricultural odor sources exist, it is important to be able to make correct attributions of odor sources when they occur. In the present study, requiring monitors to assign a descriptor to the odor as well as simultaneously recording meteorological variables allowed us to better understand the frequency of odor emissions and avoid misattributions of the odor source.

The presence of odor has led to health concerns in communities surrounding CAFOS. These concerns include both respiratory and neurobehavioral effects.<sup>32</sup> Health effects have been largely self-reported, however, and some of the effects are likely perceived to be associated with odor. Schiffman et al.<sup>13</sup> found that none of the objective health indicators that the authors evaluated, including blood pressure, temperature, heart rate, respiratory rate, lung function, nasal inflammation, secretory immunity, mood, attention, and memory, were associated with an average hog odor Nasal Ranger D/T reading of 56. Test subjects, however, were more likely to report headache, eye irritation, and nausea. The subjects were exposed in a building immediately adjacent to a swine facility, and the hog odor was delivered via a pipe that ran from the hog facility to the testing facility. Test subjects would obviously have been aware of the source of the odor. Because the average D/T reading was 56, D/T readings

could have been higher. In the current study, for 2008–2009, only 11 of the readings for hog odor were of D/T > 7:1 (8 at 7:1; 1 each at 15:1, 30:1, and 60:1). A better understanding of the odors from CAFOs such as that provided by the current study should help provide a more objective assessment of the health complaints in communities surrounding CAFOs.

Monitoring in the current study has continued to the present, with slight refinements to include simultaneous, rather than alternating, odor readings by the two monitors and several additional descriptors on the odor wheel (i.e., hog animal vs. hog manure, chicken manure). These data were not available, however, for the current analysis. The additional data will certainly form the largest database of odor monitoring ever conducted near a swine CAFO. Additional studies, however, should be conducted near other CAFOs, and we believe that the current study provides an excellent protocol for such studies. Finally, although the human nose serves as the best sentinel of the various constituents responsible for “odor,” it would also be of interest to concurrently measure different constituents (e.g., H<sub>2</sub>S, ammonia) to determine how they may affect odor and whether they or other compounds can serve as appropriate surrogates for monitoring odor perception at varying distances from the source.

## CONCLUSION

In this study, we monitored the frequency of elevated odors near a CAFO from a single site located 1046 and 1270 m distant from the nearest barn and lagoon, respectively. Monitoring was conducted on a daily basis for approximately 9 months per year over a 3-year period. Meteorological conditions were found to play an important role on the frequency of odors. Wind speed, in particular, played a significant role. Log wind speed was negatively correlated with both odor and odor from hog manure of D/T  $\geq$  7:1. Temperature was negatively correlated with odor from any source of D/T  $\geq$  7:1 but not with odor from hog manure of D/T  $\geq$  7:1. Obviously, the results from this study cannot be extrapolated to all situations involving odor complaints near a CAFO or other potential odor sources, as variation in geographic features could yield different results. Nevertheless, the use of the Nasal Ranger, when applied in a consistent manner and a standardized odor monitoring program, can provide a comprehensive picture of the ambient odor environment over time and can be used to verify odor complaints as well as clarify when the source of an odor is misattributed.

## ACKNOWLEDGMENTS

The Authors would like to thank Premium Standard Farms, LLC, for providing the financial support for the data collection. The Authors also would like to thank the personnel from TRC Companies, Inc., for on-site project management and maintenance of the odor database. The Authors are especially grateful to all of the monitors who took part in this study, as their many hours of effort and their professionalism in data collection helped build one of the largest odor databases for a single location. The Authors would like to thank Ms. Jacqueline Boltz for her assistance in editing of the manuscript.

## REFERENCES

- O'Neill, D.H.; Philips, V.R. A Review of the Control of Odour Nuisance from Livestock Buildings; *J. Agric. Eng. Res.* **1992**, *53*, 23-50.
- Moeller, S.J.; Goodwin, R.N.; Johnson, R.K.; Mabry, J.W.; Mabry, J.W.; Bass, T.J.; Robison, O.W. The National Pork Producers Council Maternal Line National Genetic Evaluation Program: A Comparison of Six Maternal Genetic Lines for Female Productivity Measures over Four Parities. *J. Anim. Sci.* **82**, 41-53.
- Schulte, D.D. Critical Parameters for Emissions. In *Proceedings of Ammonia and Odour Control from Animal Production Facilities, the International Symposium, October 6-10, 1997*; Dutch Society of Agricultural Engineering; Vinkeloord, The Netherlands; Vol. 1, pp 23-34.
- Cai, L.; Koziel, J.A.; Lo, Y.C.; Hoff, S.J. Characterization of VOCs and Odorants Associated with Swine Barn Particulate Matter Using SPME and Gas Chromatography-Mass Spectrometry-Olfactometry; *J. Chromatogr. A* **2006**, *1102*, 60-72.
- Powers, W.; Bastyr, S. *Downwind Air Quality Measurements from Poultry and Livestock Facilities*; Animal Industry Report. Iowa State University: Ames, 2004.
- Schiffman, S.S.; Bennett, J.L.; Raymer, J.H. Quantification of Odours and Odorants from Livestock Operations in North Carolina; *Agric. Forest Meteorol.* **2001**, *108*, 213-240.
- Chen, Y.; Bundy, D.; Hoff, S. Using Olfactometry to Measure Intensity and Threshold Dilution Ratio for Evaluating Swine Odor; *J. Air Waste Manage. Assoc.* **1999**, *49*, 847-853.
- Dalton, P.; Smeets, M. Olfactometry: The Human Nose as Detection Instrument. In *Handbook of Human Factors and Ergonomic Methods*; Stanton, N., Hedge, A., Brookhuis, K., Salas, E., Hendrick, H., Eds.; CRC Press: Boca Raton, FL, 2002; pp 1-8.
- A Review of the Science and Technology of Odor Measurement*; Prepared for the Iowa Department of Natural Resources; St. Croix Sensory, Inc.: Lake Elmo, MN; 2005. [http://www.iowadnr.gov/air/afo/files/odor\\_measurement.pdf](http://www.iowadnr.gov/air/afo/files/odor_measurement.pdf) (accessed June 1, 2011).
- Huey, N.A.; Broering, L.C.; Jutze, G.A.; Gruber, C.W. Objective Odor Pollution Control Investigations; *J. Air Pollut. Control Assoc.* **1960**, *10*, 441.
- Rules of Department of Natural Resources, Division 10—Air Conservation Commission, Chapter 3—Air Pollution Control Rules Specific to the Outstate Missouri Area, 10 CSR 10-6.090, (5)(C)1. <http://www.sos.mo.gov/adrules/csr/current/10csr/10c10-3.pdf> (accessed October 25, 2011).
- Sheffield, R.E.; Chahine, M.; Dye, B.; Thompson, M.B. Odor Concentrations Downwind of Idaho Dairies and Heifer Facilities; *Trans. ASABE* **2007**, *50*, 255-263.
- Schiffman, S.S.; Studwell, C.E.; Landerman, L.R.; Berman, K.; Sundy, J.S. Symptomatic Effects of Exposure to Diluted Air Sampled from a Swine Confinement Atmosphere on Healthy Human Subjects; *Environ. Health Perspect.* **2005**, *113*, 567-576.
- Jacobson, L.D.; Guo, H.; Schmidt, D.R.; Nicolai, R.E.; Zhu, J.; Janni, K.A. Development of the OFFSET Model for Determination of Odor-Annoyance-Free 3–53 Setback Distances from Animal Production Sites: Part I: Review and Experiment; *Trans. ASAE* **2005**, *48*(6); 2259-2268.
- Hoff, S.J.; Bundy, D.S. Modeling Odor Dispersion from Multiple Sources to Multiple Receptors. In *Proceedings of the International Symposium on Gaseous and Odour Emissions from Animal Production Facilities, June 1-4, 2003*; Norsens: Denmark, 2003; pp 331-339.
- McGinley, M.A.; McGinley, C.M. Developing a Credible Odour Monitoring Program. In *American Society of Agricultural Engineers (ASAE) 2004 Annual Conference, Ottawa, Canada, August 1-4, 2004*.
- Missouri Department of Environmental Resources. *Guide to Animal Feeding Operations*; PUB00915; Water Protection Program Fact Sheets, 2008. <http://www.docstoc.com/docs/3444890/Guide-to-Animal-Feeding-Operations-Water-Protection-Program-fact-sheet> (accessed October 25, 2010).
- Missouri Department of Environmental Resources. *Guide to Animal Feeding Operations*; PUB00915; Water Protection Program Fact Sheets, 2010. <http://www.dnr.mo.gov/pubs/pub915.pdf> (accessed October 25, 2011).
- Cheng, J.; Pace, J.; Zering, K.D.; Barker, J.C.; Roos, K.F.; Saele, L.M. Evaluation of Alternative Swine Waste Treatment Systems in Comparison with a Traditional Lagoon System. In *Proceedings of the Eighth International Symposium on Animal, Agricultural, and Food Processing Wastes*. Moore, J.A., Ed.; ASAE: St. Joseph, MI, 2000; pp 679-686.
- Determination of Odorants in Ambient Air by Field Inspections*; Verein Deutscher Ingenieure 3940; Beuth: Berlin, 1993.
- Air Quality—Determination of Odour Concentration by Dynamic Olfactometry*; CEN/TC264/WG2/N222e; European Committee for Standardization: Delft, Brussels, 1997.
- NVN 2820, *Provisional Standard: Air Quality. Sensory Odour Measurement Using an Olfactometer*; Netherlands Normalization Institute: Des Moines, Iowa, October 9-11, 2000. The Netherlands, March 1996.
- van Harreveld, A.P.; Heeres, P.; Harssema, H. A Review of 20 Years of Standardization of Odor Concentration Measurement by Dynamic Olfactometry in Europe; *J. Air Waste Manage. Assoc.* **1999**, *49*, 705-715.
- Nasal Ranger® Field Olfactometer, Operations Manual, Version 6.2*; St. Croix Sensory, Inc.: Lake Elmo, MN, 2008. <http://www.nasalranger.com/Operations/Nasal%20Ranger%20Operations%20Manual%20v6.2.pdf> (accessed October 25, 2011).
- Dalton, P.; Wysocki, C.J. The Nature and Duration of Adaptation Following Long-Term Odor Exposure; *Percept. Psychophys.* **1996**, *58*, 781-792.
- Dalton, P.; Wysocki, C.J.; Brody, M.J.; Lawley, H.J. Perceived Odor, Irritation, and Health Symptoms Following Short-Term Exposure to Acetone; *Am. J. Ind. Med.* **1997**, *31*, 558-569.
- Abraham, M.H.; Sanchez-Moreno, R.; Cometto-Muñiz, J.E.; Cain, W.S. A Quantitative Structure-Activity Analysis on the Relative Sensitivity of the Olfactory and the Nasal Trigeminal Chemosensory Systems; *Chem. Senses* **2007**, *32*, 711-719.
- Pan, L.; Yang, S.X.; DeBruyn, J. Factor Analysis of Downwind Odours from Livestock Farms; *Biosyst. Eng.* **2007**, *96*, 387-397.
- Wing, S.; Horton, R.A.; Marshall, S.W.; Thu, K.; Tajik, M.; Schinasi, L.; Schiffman, S.S. Air Pollution and Odor in Communities Near Industrial Swine Operations; *Environ. Health Perspect.* **2005**, *116*, 1362-1368.
- Guo, H.; Dehod, W.; Feddes, J.; Lague, C.; Edeogu, I. Monitoring Odor Occurrence in the Vicinity of Swine Farms by Resident Observers, Part I: Odor Occurrence Profiles; *Can. Biosyst. Eng. J.* **2005**, *47*, 6.57-6.65.
- Guo, H.; Dehod, W.; Feddes, J.; Lague, C.; Edeogu, I. Monitoring Odor Occurrence in the Vicinity of Swine Farms by Resident Observers, Part II: Impact of Weather Conditions on Odor Occurrence; *Can. Biosyst. Eng. J.* **2006**, *48*, 6.23-6.29.
- The Pew Commission. *Putting Meat on the Table: Industrial Farm Animal Production in America: A Report of the Pew Commission on Industrial Farm Animal Production*; A Project of The Pew Charitable Trusts and Johns Hopkins Bloomberg School of Public Health; available at [http://www.livablefutureblog.com/pdf/Putting\\_Meat\\_on\\_Table\\_FULL.pdf](http://www.livablefutureblog.com/pdf/Putting_Meat_on_Table_FULL.pdf) (accessed January, 2011).

**About the Authors**

Pamela Dalton, Ph.D., M.P.H., is a senior faculty member at the Monell Chemical Senses Center in Philadelphia, PA. Dr. Dalton has testified on behalf of defendants in swine odor nuisance cases. Edward A. Caraway is a Research Associate at West Texas A&M University, Canyon, Texas. Mr. Caraway has testified on behalf of both defendants and plaintiffs in animal and poultry odor cases. Herman Gibb, Ph. D., M.P.H., is the President of Tetra Tech Sciences, headquartered in Arlington, VA, and a Professorial Lecturer at the George Washington University School of Public Health, Washington, DC. Dr. Gibb has testified on behalf of defendants in swine odor cases. Ms. Keri Fulcher is an Associate Scientist at Tetra Tech Sciences. Please address correspondence to: Pamela Dalton, Monell Chemical Senses Center, 3500 Market Street, Philadelphia, PA 19104, USA; phone 267-519-4810; e-mail: pdalton@pobox.upenn.edu.