The Society for engineering in agricultural, food, and biological systems

CSAE SCGR The Canadian Society for Engineering in Agricultural, Food, and Biological Systems

Paper Number: 044123
An ASAE Meeting Presentation

Odor Assessments of Idaho Livestock Farms

Ronald E. Sheffield, Assistant Professor and Extension Waste Management Engineer
Department of Biological and Agricultural Engineering, University of Idaho – Twin Falls Research & Extension Center, email: rons@uidaho.edu

Matthew Thompson, Lead Engineer
Idaho Department of Agriculture, mwthompson@agri.state.id.us

Written for presentation at the
2004 ASAE/CSAE Annual International Meeting
Sponsored by ASAE/CSAE
Fairmont Chateau Laurier, The Westin, Government Centre
Ottawa, Ontario, Canada
1 - 4 August 2004

Abstract.
Odor and gas emissions were sampled on 38 dairies and 15 feedlots in southern Idaho. Odor strength was measured using a "Nasal Ranger" Field Olfactometer and n-butanol to analyze for detection threshold and odor intensity, respectively. Gas emissions for total reduced sulfur (hydrogen sulfide) was measured at the farm's most probable odor source, 50 meters downwind and 200 meters downwind, using a "Jerome Meter" (Model 631), and ammonia was measured using Dragger diffusion tubes. Facility waste handling systems and management were found to have the greatest effect on odor emission verses facility size. There were individual facilities within each subject group which emitted odors much less and up to double the group averages. Flush freestall and scrape freestall systems were shown to have the greatest measured odor emissions, while open lot facilities had lower measured levels. Odor emissions from openlot beef facilities were found to be similar to those of open lot dairy facilities. Porous geotextile covers used on secondary manure separation basins were found to be effective in reducing odor emissions by half.

Keywords. Concentrated Animal Feeding Operations (CAFO), dairy, beef, feedlots, odor

Justification

Over the past decade, an increasing number of large confined animal feeding operations (CAFOs) have been built. This intensification has been driven by the economics of domestic and export markets of meat, poultry, milk, milk protein concentrates, and eggs. CAFOs produce large quantities of manure that may cause odors and gas emissions. An ever-increasing rural population is becoming involved in many conflicts with livestock and poultry producers. The people living nearby these feeding operations are most impacted by the odors produced by the farms.

There is very little scientific information available about odor and airborne emissions (Table 1) from livestock operations (NRC, 2003). These estimates are complicated by various factors affecting the amounts and dispersion of emissions in the atmosphere. Factors may include: the type of animals; housing and production system; diet and ration; manure handling, storage and treatment system; geographic region, topography, weather conditions; and mitigation or control practices/technologies (Sheffield and Bottcher, 1999). Emissions of odor and airborne pollutants estimated by one species, location or production system may not accurately be translated to others.

Accurate estimation of air emissions from CAFOs is needed to predict their potential adverse impacts and to facilitate the selection of the most effective control measures. The US Environmental Protection Agency (EPA), the USDA Natural Resources Conservation Service (NRCS), as well as state and local governments, are seeking such information to assist them in making appropriate policy decisions to manage existing CAFOs, as well as plan for the construction, expansion or retrofits of CAFOs in their jurisdiction.

Many states and local areas have established odor regulations and thresholds to assist them in addressing and responding to odor complaints from CAFOs and other facilities (Table 2). The majority of these standards are based on using a Scentometer, and have developed established thresholds that can not be exceeded at property lines or at residences. In the absence of a numeric standard, several states (RI. SC, VT, WY, and ID) have given regulatory agencies authority to address odor issues if adverse odors are detected offsite.

Previous Work

Relatively few researchers have attempted to quantify odor and gas emissions rates from either animal housing or manure storage units (NRC, 2003 and Bicudo et al., 2003). The emission rate values that have been reported vary widely due to the lack of standardized methods used to measure, calculate, and report odor and gas emission rates. Calculation methods to quantify odor or gas emission rates from building and storage are dependant on accurate air sampling methods and proper determination of ventilation rates (Bicudo, et al., 2003) or air velocity rates.

The majority of odor and emission estimates on North American livestock facilities has been conducted in the past decade and has largely been focused on Midwestern swine production facilities. Jacobson et al. (2001) listed emission rates from swine housing systems from 13 studies. The odor emission rates from North American swine facilities varied from 3.4 to 47.7 OU/s-m^2 for nursery pigs, 2.1 to 11.9 OU/s-m^2 for finishing pigs, 3.2 to 7.9 OU/s-m^2 for farrowing sows and 4.8 to 21.3 OU/s-m^2 for gestating sows.

Considerably fewer studies have been conducted from dairy and beef facilities, outdoor manure storage units or open feedlots. Zhu et al. (2000a) measured odor at a 200-head dairy facility in Minnesota to determine daily variation. Air samples were collected every two hours over a 12-hour period during the day. Odor flux rates varied from 0.3 to 1.8 OU/m^2-s. Ventilation rates were estimated using mass exchange rates based on carbon-dioxide (CO_2) level between the inside and outside of the buildings. Bicudo et al. (2003) measured odor and H_2S/TRS at 675-head dairy freestall facility in Minnesota. Odor emissions from the manure storage were between 7 and 10 OU/m^2-s, while emissions from the barn were between 2 to 3 OU/m^2-s. Additionally, plume measurements taken at the site by trained odor panelists, indicated a relatively small effect of dispersion on odor emission, despite high wind speed (7 mph, 60% RH, 12 ^oC) for the area. Watts et al. (1993) measured odor emission from a cattle feedlot using a portable wind tunnel and found odor emission rates from 12.5 to 725 OU/s-m^2.

The *Odor from Feedlots Setback Estimation Tool* (OFFSET) is the first tool that has been developed as a design and planning tool for predicting the potential downwind odors from livestock facilities. This algorithm, developed at the University of Minnesota, Department of Biosystems and Agricultural Engineering Department, used field collected odor emissions and the INPUFF-2 model (Zhu et al., 2000b) to systematically evaluate the effectiveness of farm manure management practices on the production of odor (Jacobson, et al. (2001). The OFFSET tool is simplified by the following equation:

$$\textbf{TOEF} = (\textbf{A} \times \textbf{B} \times \textbf{C}) / 10,000$$

Where,

TOEF = Total Odor Emission Factor

A = Tabulated Odor Emission Number (representing the odor emission per square foot from the type of animal production or manure storage facility) OEN/ft^2.

B = Area (surface area of each manure storage or production facility) ft^2.

C = Odor Control Factor (1 - % reduction of odor control technology used)

Data collected during the development of OFFSET (Jacobson, et. al, 2000) created a database of average odor emissions from livestock housing facilities of various species and manure handling practices that are typical in Minnesota and the upper Midwest. OFFSET also proposes an average reduction of odor for several odor control technologies.

OFFSET also predicts the level and frequency of odor that can be expected downwind of a CAFO. Odor annoyance-free frequencies are based on the average weather data for a given geographic area and are 99, 98, 97, 96, 94 and 91%, which represent corresponding monthly total annoying events of 7, 15, 22, 20, 44 and 66 hours, respectively (Jacobson et al., 2001). These annoying frequencies should predict the number or relative level of complaints from neighbors.

Idaho's Agriculture Odor Rule

In 2001 the Idaho Legislature adopted the Rules Governing Agriculture Odor Management IDAPA 02.04.16. These rules gave authority to the Idaho Department of Agriculture to regulate odor management on agricultural operations in Idaho. The main premise in the rule was centered around accepted agricultural practices. The ISDA was to determine whether an operation was emitting odors in excess of those normally associated with accepted agricultural practices in Idaho. This lead to industry and the public to feeling that this criteria was too subjective, and in the 2002 Legislative session, the definition of odor was changed to include "the standards for which shall be judged on criteria that shall include intensity, duration, frequency, offensiveness and health risks." ISDA elected to determine this criteria through negotiated rulemaking with public and industry representatives working together with ISDA to formulate a rule that would incorporate numeric criteria for odor management. It was determined that not enough information was available to make a responsible numeric rule so the University and ISDA were charged to obtain the information necessary to support a numeric rule to be developed by the rule committee.

During this study, commonly referred to as Phase II, odor assessments of livestock farms were conducted by a panel of trained assessors coordinated by the University of Idaho. Findings of this study will be presented to the Odor Rule Committee coordinated by the Idaho Department of Agriculture as supporting information for establishing detection methods and threshold levels to manage agricultural odors.

Methodology

Emissions from Livestock Farms

Odor and gas samples were collected on and adjacent to 36 dairy and 15 beef feeding operations in southern Idaho between the August, 2003 and the April, 2004. The following treatments were used in this study:

- Dairy: Corrals with less than 1,000-head (9 facilities)
- Dairy: Corrals with more than 1,000-head (10 facilities)
- Dairy: Freestall barns with scraped/vacuum manure handling systems (9 facilities)
- Dairy: Freestall barns with recycled flush water manure handling systems (10 facilities)
- Beef Feedlots (11 facilities)
- Calf Facilities (4 facilities)

Prior to sampling, the most probable odor source on each of the volunteer study farms were identified by the investigator. Odors were assessed once per season for a year on each of the study farms. During each sampling/application day, samples were taken at distances of 200 m (656 ft), 50 m (164 ft) and adjacent to each odor source (Figure 2). During each sampling event, panelists quantified the odor concentration (Dilution to Threshold – DT), using a calibrated "Nasal Ranger"™, and the odor intensity (Table 3), as compared to n-butanol, odor threshold and odor acceptability. Gas concentrations in the field were estimated using a "Jerome Meter", for total reduced sulfur/hydrogen sulfide, and Dragger diffusion tube for ammonia. Wind speed, wind direction, temperature, and relative humidity were recorded at the odor source and at each downwind sampling location.

Odor Parameters used in this Study

Combinations of analytical and subjective odor methods were used by panelists in this study. These measurements (Table 3) were made to provide a dynamic description of the odor present at the study sites to provide analytical data for comparisons, as well as developing support information to assist the investigators in interpreting the results of this study.

Odor Panel Selection and Management

Odor assessments were conducted by a panel of trained assessors from the University of Idaho, the Idaho Department of Agriculture and the Idaho Department of Environmental Quality. Panelists were selected from a group of 55 candidates from the three organizations following ASTM Standard E 544-99, selecting for the highest accuracy to known n-butanol standards and least variable responses to unknown liquid odorous samples. From the results of the intensity evaluation, a panel of 9 field assessors and 2 alternates were selected and trained by University of Idaho personnel how to operate the “Nasal Ranger” field olfactometer and to evaluate odor intensity using n-butanol. Additionally, four technicians were trained and used to collect air and gas samples and to manage the team of panelists. Prior to beginning the study, two days of field training was conducted on 6 dairies and panelists participated in a 6 week odor methodology study during January and February, 2003 (Sheffield et al., 2004). A Quality Assurance/Quality Control (QA/QC) protocol was developed to describe how samples would be collected according to manufacture’s guidelines, transported, entered, reviewed and reported.

On each sampling day, four (4) panelists conducted odor assessments using the “Nasal Ranger” field olfactometer, and odor intensity (as compared to n-butanol). During each evaluation, the panelists determined the detection threshold (DT) of the odor present at each site, application event, or manure management practice. The detection threshold or dilutions to threshold is defined as the number of volumes of clean air that is required to make one volume of odorous air non-detectable by each panelist. The D/T is equivalent to the concentration of odor or the amount of odor that is in the air. Panelists were required to select the same DT twice before the selection would be recorded.

Emission results from each assessment were reviewed by the project investigators for completeness and cataloged prior to being delivered to a third-party firm for data entry and recoding. The firm was secured to provide a blinding of the data to ensure that the project investigators would not know the identity of any specific facility, but would be able to group similar facilities to report aggregated data and make generalized assumptions. Once the data was recoded, it was returned to the project investigators for data analysis and reporting.

The geometric mean of each DT, using the following equation for each of the devices, was reported and used for data analysis (Table 5). The geometric average of the geometric DTs for all the panelists was calculated for each odor assessment.

$$DT_{geo} = 10^{\frac{\log D/T_n + \log D/T_{(n+1)}}{2}}$$

Results and Discussion

Emissions from Dairy and Beef Feeding Operations in Idaho

Odor and gas emissions were sampled on 38 dairies and 15 feedlots in southern Idaho. Odor strength was measured using a “Nasal Ranger” Field Olfactometer and n-butanol to analyze for detection threshold and odor intensity, respectively. Gas emissions for total reduced sulfur (hydrogen sulfide) was measured at the farm’s most probable odor source, 50 meters downwind and 200 meters downwind, using a “Jerome Meter” (Model 631), and ammonia was measured using Dragger diffusion tubes (Tables 6 a-c). Additional measurements were taken for odor threshold and acceptability.

Average odor detection thresholds were found to be greatest at the odor source on scraped freestall dairies and lowest on openlot dairies with less than 1,000 head capacity (Table 7). Flushed freestall dairies were found to have the highest average concentrations of H_2S/TRS and NH_3. Detection threshold from all facilities were found to reduce significantly as the distance from the odor source was increased. On average, detection thresholds were reduced by 49% at a 50 meter distance and by 75% at 200 meters. Similarly, H_2S/TRS concentrations were found to reduce by 42% at a 50 meter distance and 68% at 200 meters downwind.

Within each group of dairies, at least one dairy was observed to have higher emissions compared to other similar farms. Table 8 reports the average emissions from each of the dairies in the study. Farm AL18 was found to have DT twice that of the reported average for openlot dairies less than 1,000-head. Similarly the average DT for AG21 was 42.4 while the average for openlot dairies greater than 1,000-head was 17.0. These farms, and others, illustrate that even though a significant difference in DT was found between groups that there will likely be farms, regardless of size and design, which were higher than average odor emissions.

Seasonal variations were not found to have a significant impact on odor emissions at the source or downwind (Table 9a-c). However, differences were found between each dairy group and the percentage of farms that exceeded 7, 15 and 30 dilutions to threshold (Figure 3). During the summer of 2003, 85% of scraped dairies exceeded 7DT, while during the fall and spring all of the farms were found to exceed this level at the odor source. Additionally, 71% of the farms were found to exceed 15DT at the odor source during the summer, 82% in the fall, and 89% in the spring of 2004. However, for openlot dairies less than 1,000-head, the greatest odor was observed during the fall and the lowest odor during the spring. Exceedances of the three detection thresholds were found to be greatly reduced 200 meters downwind as compared to those at the odor source (Figure 3). Generally, detection thresholds were found to exceed the 7DT level with in each group. Other exceedances (flush dairies during the fall) are likely due to high odor emissions on one or two facilities. This comparison illustrates the importance of farm setbacks plus proper siting and location of manure storage facilities on the farm.

The odor emissions from feedlots (Table 10) were found to be similar to those of larger openlot dairies. Concentrations from feedlots averaged 16.3 D/T at the odor source, 11.0 at 50 meters, and 5.9 at 200 meters downwind. However, average concentrations of H_2S/TRS on feedlots were observed to be a fraction of those observed on dairy facilities. These lower concentrations are likely due to the lower manure loading rates to runoff collection ponds and the management of feedlot surface to promote rapid drying of manure. Ammonia concentrations were moderately high, and were greatest at the feedlot facilities compared to the heifer and calf farms. The 0.061 ppm of H_2S/TRS observed at the heifer pens is likely due to the documented interference between H_2S/TRS and NH_3 documented by Sheffield, et al. (2004).

Geotextile Lagoon Covers

The installation of Geotextile covers on manure storage basins and secondary settling basins was found to dramatically reduce odor. Three samples were taken at a dairy with a 1-year old cover during the summer of 2003 and spring of 2004. The effect of the cover was compared using samples collected at the edge of covered and uncovered settling basins. Odor concentrations were found to be reduced by 50% and the odor intensity by 25% (Figure 5). Odor acceptability was found to be improved by an average of 20%. These reductions are similar to those found by Bicudo, et al. (2002) using a portable wind tunnel on a similar cover installed on a swine finishing farm in Minnesota. Contrary to the results found by Bicudo, no difference was found between concentrations of ammonia and H2S/TRS measured by Dragger tubes and a "Jerome Meter", respectively. This difference may be due to the difference in sampling techniques or site characteristics which may have influenced gas sampling results. Further studies should be conducted to quantify the effectiveness of the Geotextile covers on reducing ammonia and hydrogen sulfide emissions.

During the March, 2004 sampling period the covered lagoon and settling basins were found to be largely submerged (~40% covered). This is likely due to the accumulation and melt of winter snow on the cover. Odor concentrations during this period were found to greater than when they were re-sampled in April, 2004, after the cover became buoyant and covered approximately 95% of the basin surface. Engineers, producers and regulators need to be aware of this natural limitation of the cover following winter. Cover developers and contractors should consider either more reinforcement/support or should investigate if the pumping of accumulated liquid above the porous cover will allow the cover to float earlier during spring providing the desired treatment.

Hydrogen Sulfide, Ammonia and Odor
A Pearson's correlation analysis was conducted between odor detection threshold, odor intensity, and measurements of NH_3 and TRS/H_2S for samples taken adjacent to, 50 meters and 200 meters downwind of odor sources on the farm (Table 11). Moderate correlations were found between detection threshold and TRS/H_2S. The relationship between these parameters appears to be stronger as the distance between the odor source and the panelist is increased. This finding in similar to that found by Sheffield et al. (2004) where samples were taken adjacent to 5 odor sites during the winter of 2003. Additional analysis using numeric regression of DT and TRS/H_2S at 50 and 200 meters downwind (Figure 6) found that even though there is a moderate correlation between these parameters there is low confidence in the predictability of the relationship (R^2 = 0.19, 0.21, respectively). This finding illustrates the limitation of using gas measurements, via a "Jerome Meter" or Dragger Tubes as a matter of convenience, for a quasi-odor determination instead of making a direct odor assessment using a trained panelist.

Conclusions
Trained panelists can be an effective means of evaluating odor emissions and concentrations in the field. While variability was observed between panelists, this variability was due mostly to environmental conditions during sampling and reduced significantly during stable conditions.

Facility waste handling systems and management were found to have the greatest effect on odor emission verses facility size. There were individual facilities within each subject group which emitted odors much less and up to double the group averages. Flush freestall and scrape freestall systems were shown to have the greatest measured odor emissions, while open lot facilities had lower measured levels. Since open lot facilities occupy 2-5 times the area of the equivalent freestall system, it is difficult to make odor emission conclusions from these field measurements. Generally as the size of facilities increase, odor emissions also increase. Odor emissions from openlot beef facilities were found to be similar to those of open lot dairy facilities. Porous geotextile covers for manure storages were found to be effective in reducing odor emissions by half.

Individual gas measurements were not shown to have a high predictive correlation to odor concentration, although, TRS/H2S readings were shown to have higher correlations as distance from the odor source increased. This is likely due to the fact that many of the odorous compounds dissipate rapidly and only a few odorous compounds linger and travel longer closer to the ground. Additional research is needed to evaluate the emission of odors and gases from livestock facilities in order to develop predictive tools and models to assist producers, engineers, and regulators in developing livestock facilities that will have minimal odor impact on rural residents.

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Table 1. Classifications of air emissions from Confined Animal Feeding Operations (Adopted from

NRC, 2003).

Species	Criteria Pollutant[a]	Hazardous Air Pollutant (HAP)[a]	Greenhouse Gas (GHG)	Regulated Air Pollutant
NH_3	----	----	----	X[b]
N_2O	----	----	X[c]	----
NO_x	----	----	X	X
CH_4	----	----	X	----
VOCs[d]	Precursor to Ozone	X	X	X
H_2S	----	----	----	X[c]
PM[f] (TSP)	----	----	----	X
PM_{10}	X	----	----	----
$PM_{2.5}$	X	----	----	----
Odor	----	----	----	X[g]

[a]*Criteria Pollutant*: One of six pollutants (CO, NO_2, O_3, Pb, PM_{10}, $PM_{2.5}$, SO_2) listed by the EPA as being a primary air pollutant.; *Hazardous Air Pollutant*: One of 189 compounds and compound classes listed in the 1990 Clean Air Act Amendment as hazardous air toxin.
[b]Ammonia is not a criteria pollutant but is regulated as a precursor for secondary PM2.5, which is a criteria pollutant. Hence it may be considered a regulated air pollutant.
[c]Nitrous Ozide is not a precursor for the tropospheric ozone, but is a greenhouse gas. It is not considered to be part of NO_x (criteria pollutants NO and NO_2), which do contribute to ozone formation.
[d]Volatile Organic Compounds (VOCs), sometimes refered to as reactive organic gases (ROGs), contribute to the formation of ozone, which is a criteria pollutant.
[e]Hydrogen Sulfide is not listed as a criteria pollutant or HAP. However, it is regulated because it is listed as having a New Source Performance Standard (NSPS). It is likely to be listed as a HAP in the near future.
[f]Particulate matter. Prior to 1987, PM was a criteria pollutant and regulated as total suspended particulate (TSP). Currently, the PM fractions listed as criteria pollutants are PM_{10} and $PM_{2.5}$. However, TSP emissions are regulated in some states.
[g]Odor is regulated in some states. State air pollution regulatory agencies regulate odor based on a nuisance, odor intensity or odor concentration standard. See Table 2 for more information.

Table 2. Odor Standards/Thresholds in the United States.

States/Organizations	Odor *Measured as Dillutions to Threashold (D/T) with a Scentometer*				
	Residential	Commercial	Industrial	Other	Comments
ATSDR - Agency for Toxic Substances and Disease Registry	7			15	Property Line; Can exceed 14 days per year with notice.
Cedar Rapids, Iowa	4	8	20	8	
Chattanooga, Tennessee	0	4	4	4	
Colorado	7	7	15		Swine: 7 D/T at property line, 2 D/T at residence
Dallas, Texas	2	1	1		
District of Columbia	1	1	1		
Illinois	8	8	15	16	
Kentucky	7	7	24	16	
Lousiana					N-butanol = 6 on an 8 point scale.
Missouri	7	7	7	4	**Class 1A CAFO's** (>4900 cows; 17,500 Finish hogs; 210,00 layers)
Nevada	8	8	8		
North Dakota	2	2	2	2	
Omaha, Nebraska	4	8	20	8	
Oregon				2	
Polk County, Iowa	7	7	7	7	
Rhode Island					No emission of substance that causes an objectionable odor beyond property line.
South Carolina					No producer may cause, allow or permit emission of an undesireable odor into the ambient air unless preventive measures to abate/control the odor are utilized
Southwest WA State, AGMA	1-2	1-2	8-32	8-32	
Vermont					No emission of substance that causes an objectionable odor beyond propery line.
Washinton					Any person who allows the emission of an odor must use recognized good practices to minimize odors; Masking is not allowed.
Wyoming	7	7	7		Measured at property line

Adopted from Redwine and Lacey, 2000 and Sweeten, 1997.

Table 3. Description of Odor Parameters Used in this Study

Odor Test	Definition	Analytical Method(s)
Detection Threshold (DT)	Volume of non-odorous air needed to dilute a unit volume of air to the point where panelist begin to detect an odor.	Olfactometry; "Nasal Ranger" field olfactometer
Odor Intensity	Strength of an odor sample above the detection threshold.	N-butanol
Odor Threshold	Measure of the unpleasantness of an odor displayed as a scale: 1 (pleasant) to 10 (extremely unpleasant).	Odor Panel
Odor Acceptability	Measure of the acceptability of an odor as it would be experienced at the property line of a facility, rural residence or while hosting a party or event. Displayed as a scale: 10 (very acceptable given the location) to -10 (unacceptable odor given the location).	Odor Panel

Table 4. Equivalent concentrations of N-butanol.

Scale	Concentration N-butanol (ppm)
0	0
1	500
2	1,000
3	2,000
4	4,000
5	8,000
6	16,000

Table 5. Geometric Means of the Dilutions to Threshold for the "Nasal Ranger" Field Olfactometer.

Unit D/T	Geometric DT
60	60
30	42.4
15	21.2
7	10.2
4	5.3
2	2.8
<2	1.4

Table 6a. Emissions from the Odor Source on Idaho Animal Feeding Operations.

Average Emissions from Site								
Location	**Detection Threshold**	**Odor Intensity**	**Odor Threshold**	**Odor Acceptability at Property Line**	**Odor Acceptability at Residence**	**Odor Acceptability at Party or Event**	**H_2S/TRS**	**NH_3**
Range - units	(1.4 - 60)	(0-6)	(1-10)	(10 to -10)	(10 to -10)	(10 to -10)	(ppm)	(ppm)
Openlot Dairies <1,000-head	**11.4**	**2.8**	**3.4**	**4.1**	**-0.3**	**-2.1**	**0.063**	**0.410**
maximum	*60.0*	*6.0*	*8.0*	*-4.0*	*-7.0*	*-9.0*	*0.615*	*2.500*
Openlot Dairies >1,000-head	**17.0**	**3.7**	**4.3**	**2.3**	**-2.1**	**-4.2**	**0.078**	**0.360**
maximum	*60.0*	*6.0*	*8.0*	*-5.0*	*-9.0*	*-10.0*	*0.289*	*1.750*
Scraped Freestall Dairies	**29.0**	**4.4**	**5.7**	**-0.1**	**-4.4**	**-6.2**	**0.223**	**0.530**
maximum	*60.0*	*6.0*	*9.0*	*-7.0*	*-10.0*	*-10.0*	*2.450*	*3.000*
Flushed Freestall Dairies	**22.2**	**4.2**	**5.5**	**0.2**	**-4.1**	**-5.8**	**0.379**	**0.660**
maximum	*60.0*	*6.0*	*10.0*	*-10.0*	*-10.0*	*-10.0*	*4.938*	*3.000*
Calf Hutches	**6.6**	**1.4**	**2.1**	**6.6**	**2.6**	**0.8**	**0.007**	**0.125**
maximum	*21.2*	*2.5*	*3.5*	*2.0*	*-4.0*	*-6.0*	*0.009*	*0.250*
Heifer Pens	**29.1**	**3.8**	**3.4**	**3.5**	**0.0**	**-2.8**	**0.061**	**0.050**
maximum	*42.4*	*4.5*	*4.0*	*0.0*	*-5.0*	*-7.0*	*0.068*	*0.100*
Feedlot	**16.3**	**3.2**	**3.5**	**3.9**	**0.2**	**-2.3**	**0.019**	**0.185**
maximum	*42.4*	*6.0*	*8.0*	*-4.0*	*-6.5*	*-10.0*	*0.046*	*0.500*
Feedlot + Heifer Pens	**17.6**	**3.3**	**3.5**	**3.9**	**0.2**	**-2.4**	**0.022**	**0.177**
maximum	*42.4*	*6.0*	*8.0*	*-4.0*	*-6.5*	*-10.0*	*0.068*	*0.500*

Table 6b. Emissions from 50 meters downwind of Odor Sources on Idaho Animal Feeding Operations.

Average Emissions from 50 meters Downwind								
Location	Detection Threshold	Odor Intensity	Odor Threshold	Odor Acceptability at Property Line	Odor Acceptability at Residence	Odor Acceptability at Party or Event	H_2S/TRS	NH_3
Range - units	(1.4 - 60)	(0-6)	(1-10)	(10 to -10)	(10 to -10)	(10 to -10)	(ppm)	(ppm)
Openlot Dairies <1,000-head	**8.4**	**2.7**	**3.5**	**4.8**	**0.3**	**-1.6**	**0.038**	**0.420**
maximum	*60.0*	*5.0*	*10.0*	*-2.0*	*-9.0*	*-10.0*	*0.190*	*2.000*
Openlot Dairies >1,000-head	**4.8**	**1.8**	**2.2**	**7.1**	**3.3**	**1.9**	**0.042**	**0.270**
maximum	*42.4*	*4.0*	*6.0*	*0.0*	*-5.0*	*-9.0*	*0.119*	*1.500*
Scraped Freestall Dairies	**13.4**	**3.3**	**4.3**	**2.7**	**-1.6**	**-3.4**	**0.161**	**0.430**
maximum	*60.0*	*6.0*	*9.0*	*-5.0*	*-9.0*	*-10.0*	*1.301*	*2.000*
Flushed Freestall Dairies	**12.4**	**3.3**	**4.3**	**2.3**	**-2.2**	**-3.9**	**0.173**	**0.430**
maximum	*60.0*	*6.0*	*9.0*	*-10.0*	*-10.0*	*-10.0*	*1.890*	*2.000*
Calf Hutches	--	--	--	--	--	--	--	--
Heifer Pens	--	--	--	--	--	--	--	--
Feedlot	**11.0**	**2.4**	**2.6**	**5.9**	**1.9**	**0.1**	**0.012**	**0.086**
maximum	*60.0*	*5.5*	*8.0*	*-2.0*	*-6.0*	*-8.0*	*0.022*	*0.250*
Feedlot + Heifer Pens	--	--	--	--	--	--	--	--

"--" Indicates no data colleted at this distance.

Table 6c. Emissions from 200 meters downwind of Odor Sources on Idaho Animal Feeding Operations.

Average Emissions from 200 meters Downwind								
Location	**Detection Threshold**	**Odor Intensity**	**Odor Threshold**	**Odor Acceptability at Property Line**	**Odor Acceptability at Residence**	**Odor Acceptability at Party or Event**	**H_2S/TRS**	**NH_3**
Range - units	(1.4 - 60)	(0-6)	(1-10)	(10 to -10)	(10 to -10)	(10 to -10)	(ppm)	(ppm)
Openlot Dairies <1,000-head	**3.1**	**1.5**	**1.7**	**8.0**	**4.9**	**3.7**	**0.020**	**0.290**
maximum	*42.4*	*4.5*	*6.0*	*-3.0*	*-7.0*	*-9.0*	*0.088*	*2.000*
Openlot Dairies >1,000-head	**4.5**	**1.9**	**2.3**	**6.9**	**2.7**	**1.0**	**0.024**	**0.270**
maximum	*42.4*	*5.0*	*8.0*	*-5.0*	*-9.0*	*-10.0*	*0.092*	*2.750*
Scraped Freestall Dairies	**6.3**	**2.5**	**3.2**	**5.2**	**1.2**	**-0.5**	**0.078**	**0.260**
maximum	*60.0*	*5.0*	*10.0*	*-3.0*	*-8.0*	*-9.0*	*0.785*	*1.750*
Flushed Freestall Dairies	**8.5**	**2.8**	**3.7**	**4.2**	**0.0**	**-1.7**	**0.117**	**0.300**
maximum	*60.0*	*6.0*	*8.5*	*-7.0*	*-9.0*	*-10.0*	*0.685*	*3.000*
Calf Hutches	--	--	--	--	--	--	--	--
Heifer Pens	--	--	--	--	--	--	--	--
Feedlot	**5.9**	**1.8**	**2.1**	**7.0**	**4.5**	**3.1**	**0.006**	**0.000**
maximum	*21.2*	*5.0*	*7.0*	*-3.0*	*-5.0*	*-7.0*	*0.009*	*0.000*
Feedlot + Heifer Pens	--	--	--	--	--	--	--	--

“--" Indicates no data colleted at this distance.

Table 7. Average Emissions from Idaho Dairies.

Location	Distance	Detection Threshold	Odor Intensity	H_2S/TRS	NH_3
Range - units	meters	(1.4 – 60)	(0 – 6)	ppm	ppm
Openlot Dairies <1,000 hd	Source	11.4	2.8	0.063	0.410
	50 meters	8.4	2.7	0.038	0.420
	200 meters	3.1	1.5	0.020	0.290
Openlot Dairies >1,000 hd	Source	17.0	3.7	0.078	0.360
	50 meters	4.8	1.8	0.042	0.270
	200 meters	4.5	1.9	0.024	0.270
Scraped Freestall Dairies	Source	29.0	4.4	0.223	0.530
	50 meters	13.4	3.3	0.161	0.430
	200 meters	6.3	2.5	0.078	0.260
Flushed Freestall Dairies	Source	22.2	4.2	0.379	0.660
	50 meters	12.4	3.3	0.173	0.430
	200 meters	8.5	2.8	0.117	0.300

Table 8. Average Emissions from Study Dairies measured at the Odor Source.

Location	Detection Threshold	Odor Intensity	Odor Threshold	Odor Acceptability at Property Line	Odor Acceptability at Residence	Odor Acceptability at Party or Event	H_2S/TRS	NH_3
Range - units	(1.4 - 60)	(0-6)	(1-10)	(10 to -10)	(10 to -10)	(10 to -10)	(ppm)	(ppm)
Openlot Dairies <1,000-head								
AVERAGE	***11.4***	***2.8***	***3.4***	***4.1***	***-0.3***	***-2.1***	***0.063***	***0.410***
AL14	9.8	2.6	2.8	4.6	0.8	-1.2	0.021	0.308
AL15	6.8	2.6	3.4	3.5	-1.1	-3.4	0.020	0.308
AL18	24.5	3.6	4.9	1.2	-3.3	-5.0	0.291	0.689
AL24	14.9	3.4	3.6	2.4	-3.1	-4.6	0.019	0.042
AL28	2.3	1.3	1.3	8.8	6.3	5.5	0.035	0.225
AL29	10.7	3.2	3.5	4.0	-0.7	-2.3	0.044	0.728
AL31	12.5	3.4	4.0	3.8	-1.6	-4.0	0.028	0.314
AL33	7.9	1.5	2.3	7.1	2.7	1.7	0.021	0.361
AL38	17.7	3.0	3.3	3.8	0.2	-2.1	0.026	0.297
Openlot Daries >1,000-head								
AVERAGE	***17.0***	***3.7***	***4.3***	***2.3***	***-2.1***	***-4.2***	***0.078***	***0.360***
AG11	18.6	4.1	3.8	1.8	-3.1	-5.2	0.061	0.136
AG13	9.2	3.5	3.5	2.8	-1.0	-3.8	0.041	0.328
AG17	21.1	3.4	4.1	3.2	-1.4	-3.1	0.058	0.517
AG21	42.4	5.8	7.3	-3.3	-7.3	-9.0	0.180	0.267
AG22	19.3	3.8	4.6	1.4	-2.7	-4.7	0.095	0.844
AG25	10.6	3.1	3.1	4.8	0.3	-1.6	0.025	0.417
AG32	27.4	3.9	5.3	1.4	-3.0	-5.0	0.127	0.200
AG34	25.2	3.8	4.6	2.5	-3.5	-5.5	0.033	0.150
AG36	10.6	3.2	3.9	3.6	-0.7	-2.9	0.074	0.317
AG39	22.7	3.5	5.5	0.8	-3.3	-5.0	0.211	0.000
Scraped Freestall Dairies								
AVERAGE	***29.0***	***4.4***	***5.7***	***-0.1***	***-4.4***	***-6.2***	***0.223***	***0.530***
AS41	25.7	4.7	6.1	-0.4	-4.8	-6.8	0.156	0.358
AS44	35.7	4.6	5.3	-0.8	-5.0	-6.8	0.085	0.373
AS45	37.7	4.9	6.2	-0.7	-5.1	-6.8	0.080	0.167
AS46	43.5	5.5	7.3	-2.6	-6.5	-8.2	0.473	1.447
AS51	53.4	5.5	7.2	-2.3	-6.5	-8.2	0.251	0.256
AS52	13.8	3.3	4.2	2.7	-1.6	-3.3	0.022	0.056
AS57	35.7	4.6	5.3	-0.8	-4.8	-6.3	0.117	0.233
AS61	28.3	3.7	4.5	1.4	-2.8	-4.6	0.114	1.194
AS65	17.1	3.8	5.0	1.7	-3.0	-5.1	0.581	0.503
Flushed Freestall Dairies								
AVERAGE	***22.2***	***4.2***	***5.5***	***0.2***	***-4.1***	***-5.8***	***0.379***	***0.660***
AF41	39.7	4.8	6.1	-0.4	-4.8	-6.8	0.235	0.742
AF42	31.7	4.9	6.4	-1.7	-5.8	-7.1	0.326	0.567
AF47	20.6	4.7	4.8	0.2	-4.6	-7.0	0.144	1.053
AF53	15.9	4.1	6.0	-0.7	-3.6	-5.0	0.744	1.246
AF56	22.0	4.0	5.7	0.2	-4.9	-6.1	0.214	0.250
AF58	28.0	4.7	5.5	0.9	-4.2	-5.9	0.178	0.417
AF59	16.7	3.6	5.1	1.6	-2.5	-4.8	0.045	0.417
AF62	13.8	3.5	4.1	2.3	-2.5	-3.8	0.216	0.419
AF64	21.6	4.6	6.0	-1.0	-4.5	-6.5	0.074	0.856
AF67	18.9	4.2	4.9	1.5	-3.1	-5.0	0.119	0.292

Table 9a. Seasonal Emissions adjacent to Odor Sources on Idaho Dairies.

Location	Detection Threshold	Odor Intensity	Odor Threshold	Odor Acceptability at Property Line	Odor Acceptability at Residence	Odor Acceptability at Party or Event	H_2S/TRS	NH_3
Range - units	(1.4 - 60)	(0-6)	(1-10)	(10 to -10)	(10 to -10)	(10 to -10)	(ppm)	(ppm)
Average Emissions from Source during the Summer								
Openlot Dairies <1,000-head	**13.0**	**2.5**	**3.0**	**5.3**	**0.9**	**-1.0**	**0.062**	**0.539**
Openlot Dairies >1,000-head	**21.4**	**3.6**	**4.5**	**2.2**	**-2.6**	**-4.9**	**0.078**	**0.313**
Scraped Freestall Dairies	**32.4**	**4.2**	**5.5**	**0.2**	**-4.0**	**-5.9**	**0.370**	**0.607**
Flushed Freestall Dairies	**33.3**	**4.9**	**6.0**	**-0.4**	**-5.2**	**-7.0**	**0.207**	**0.925**
Average Emissions from Source during the Fall								
Openlot Dairies <1,000-head	**16.6**	**3.1**	**3.5**	**2.8**	**-1.9**	**-3.8**	**0.027**	**0.217**
Openlot Dairies >1,000-head	**16.5**	**3.5**	**3.8**	**3.3**	**-0.8**	**-2.5**	**0.061**	**0.410**
Scraped Freestall Dairies	**35.0**	**4.6**	**6.0**	**0.1**	**-4.0**	**-5.8**	**0.159**	**0.695**
Flushed Freestall Dairies	**30.1**	**4.3**	**5.6**	**0.1**	**-3.6**	**-5.1**	**0.329**	**0.465**
Average Emissions from Source during the Spring								
Openlot Dairies <1,000-head	**16.6**	**3.1**	**3.5**	**2.8**	**-1.9**	**-3.8**	**0.027**	**0.217**
Openlot Dairies >1,000-head	**21.6**	**4.0**	**4.6**	**0.7**	**-3.4**	**-5.4**	**0.105**	**0.395**
Scraped Freestall Dairies	**33.0**	**5.1**	**6.0**	**-1.3**	**-5.9**	**-7.4**	**0.113**	**0.324**
Flushed Freestall Dairies	**22.0**	**4.1**	**5.0**	**0.5**	**-4.0**	**-6.0**	**0.094**	**0.547**

Table 9b. Seasonal Emissions 50-meters downwind of Odor Sources on Idaho Dairies.

Location	Detection Threshold	Odor Intensity	Odor Threshold	Odor Acceptability at Property Line	Odor Acceptability at Residence	Odor Acceptability at Party or Event	H_2S/TRS	NH_3
Range - units	(1.4 - 60)	(0-6)	(1-10)	(10 to -10)	(10 to -10)	(10 to -10)	(ppm)	(ppm)
Average Emissions from 50 meters downwind of Odor Source during the Summer								
Openlot Dairies <1,000-head	**7.1**	**1.9**	**2.5**	**7.1**	**2.9**	**1.1**	**0.040**	**0.500**
Openlot Dairies >1,000-head	**11.8**	**2.5**	**3.5**	**5.3**	**0.3**	**-1.9**	**0.047**	**0.389**
Scraped Freestall Dairies	**17.7**	**3.0**	**4.1**	**3.6**	**-0.7**	**-2.5**	**0.337**	**0.469**
Flushed Freestall Dairies	**21.6**	**3.8**	**4.8**	**1.9**	**-3.3**	**-5.4**	**0.307**	**0.683**
Average Emissions from 50 meters downwind of Odor Source during the Fall								
Openlot Dairies <1,000-head	**5.3**	**1.8**	**1.9**	**6.4**	**1.8**	**0.6**	**0.026**	**0.410**
Openlot Dairies >1,000-head	**9.3**	**2.6**	**3.2**	**5.4**	**1.8**	**0.1**	**0.035**	**0.229**
Scraped Freestall Dairies	**18.5**	**3.4**	**4.4**	**2.4**	**-1.5**	**-3.5**	**0.069**	**0.563**
Flushed Freestall Dairies	**20.0**	**3.6**	**4.3**	**2.7**	**-1.2**	**-2.9**	**0.123**	**0.357**
Average Emissions from 50 meters downwind of Odor Source during the Spring								
Openlot Dairies <1,000-head	**5.3**	**1.8**	**1.9**	**6.4**	**1.8**	**0.6**	**0.026**	**0.410**
Openlot Dairies >1,000-head	**12.5**	**3.2**	**3.8**	**2.8**	**-2.0**	**-4.0**	**0.042**	**0.130**
Scraped Freestall Dairies	**19.2**	**3.6**	**4.4**	**1.9**	**-2.9**	**-4.5**	**0.048**	**0.183**
Flushed Freestall Dairies	**13.3**	**3.0**	**3.8**	**2.4**	**-1.7**	**-3.0**	**0.078**	**0.113**

Table 9c. Seasonal Emissions 200-meters downwind of Odor Sources on Idaho Dairies.

Location	Detection Threshold	Odor Intensity	Odor Threshold	Odor Acceptability at Property Line	Odor Acceptability at Residence	Odor Acceptability at Party or Event	H_2S/TRS	NH_3
Range - units	(1.4 - 60)	(0-6)	(1-10)	(10 to -10)	(10 to -10)	(10 to -10)	(ppm)	(ppm)
Average Emissions from 200 meters downwind of Odor Source during the Summer								
Openlot Dairies <1,000-head	**5.3**	**1.9**	**2.0**	**7.9**	**4.2**	**2.6**	**0.026**	**0.425**
Openlot Dairies >1,000-head	**7.5**	**1.7**	**2.2**	**6.1**	**1.9**	**0.0**	**0.027**	**0.500**
Scraped Freestall Dairies	**7.8**	**2.1**	**2.8**	**6.4**	**3.0**	**1.3**	**0.138**	**0.321**
Flushed Freestall Dairies	**13.3**	**3.1**	**4.1**	**3.7**	**-1.5**	**-3.5**	**0.148**	**0.333**
Average Emissions from 200 meters downwind of Odor Source during the Fall								
Openlot Dairies <1,000-head	**2.1**	**0.8**	**1.1**	**8.8**	**6.1**	**5.2**	**0.006**	**0.036**
Openlot Dairies >1,000-head	**4.6**	**2.3**	**2.5**	**6.3**	**2.5**	**0.9**	**0.027**	**0.086**
Scraped Freestall Dairies	**7.0**	**2.7**	**3.1**	**5.4**	**1.2**	**-0.5**	**0.044**	**0.357**
Flushed Freestall Dairies	**15.8**	**3.5**	**4.3**	**2.8**	**-1.6**	**-3.3**	**0.140**	**0.145**
Average Emissions from 200 meters downwind of Odor Source during the Spring								
Openlot Dairies <1,000-head	**2.1**	**0.8**	**1.1**	**8.8**	**6.1**	**5.2**	**0.006**	**0.036**
Openlot Dairies >1,000-head	**2.9**	**0.8**	**1.1**	**8.1**	**4.5**	**3.3**	**0.009**	**0.000**
Scraped Freestall Dairies	**11.5**	**2.7**	**3.9**	**3.3**	**-1.5**	**-2.9**	**0.034**	**0.020**
Flushed Freestall Dairies	**3.4**	**1.3**	**1.5**	**8.1**	**5.6**	**4.7**	**0.010**	**0.000**

Table 10. Average Emissions from Idaho Beef and Heifer Feedlots.

Location	Distance	Detection Threshold	Odor Intensity	H_2S/TRS	NH_3
Range - units	meters	(1.4 – 60)	(0 – 6)	ppm	ppm
Calf Hutches	Source	6.6	1.4	0.007	0.125
	50 meters	- -	- -	- -	- -
	200 meters	- -	- -	- -	- -
Heifer Pens	Source	29.1	3.8	0.061	0.050
	50 meters	- -	- -	- -	- -
	200 meters	- -	- -	- -	- -
Feedlots	Source	16.3	3.2	0.019	0.185
	50 meters	11.0	2.4	0.12	0.086
	200 meters	5.9	1.8	0.006	0.000
Feedlot + Heifer Pens	Source	17.6	3.3	0.022	0.177
	50 meters	- -	- -	- -	- -
	200 meters	- -	- -	- -	- -

"- -" Indicates no data colleted at this distance.

Table 11. Correlation between Odor Detection Threshold, Hydrogen Sulfide and Ammonia.

Distance	D/T vs TRS/H_2S	D/T vs NH_3
0 meters (Odor Source)	0.523	0.227
50 meters	0.625	0.336
200 meters	0.664	0.215

Pierson's Correlation Coefficients (1.000 indicates true relationship between parameters)

Figure 1. Odor Sampling Schematic.

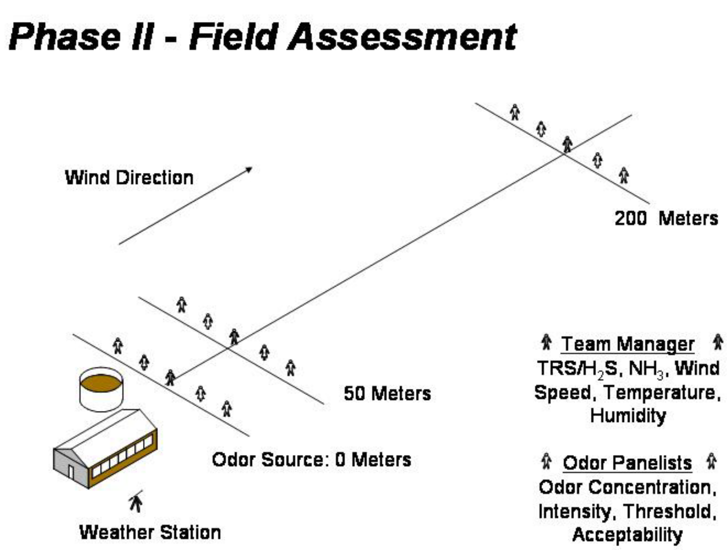

Figure 2. Percentage of Dairies above Three Odor Detection Levels Measured at the Odor Source.

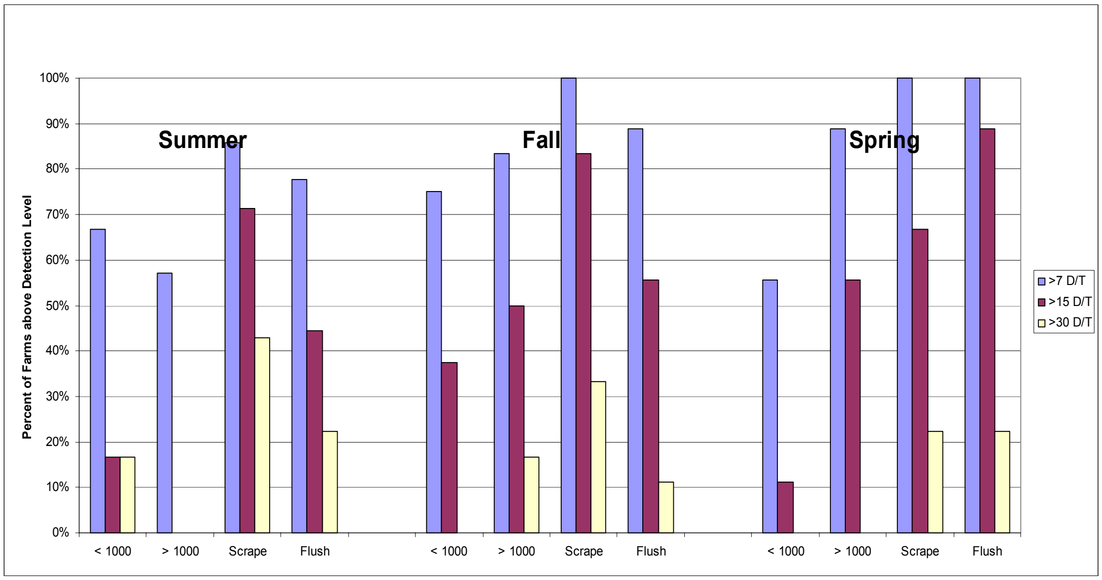

Figure 3. Percentage of Dairies above Three Odor Detection Levels Measured 200 Meters downwind of the Odor Source.

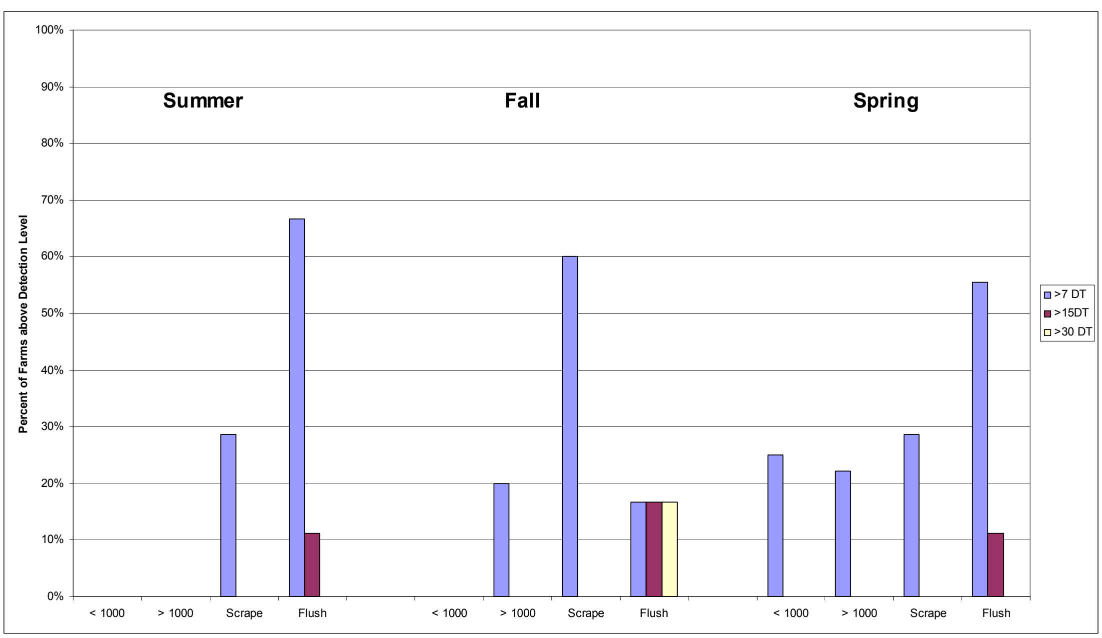

Figure 4. Comparison of Odor Emissions from Covered and Uncovered Second-Stage Dairy Solids Separation Basins as measured by "Nasal Ranger" (DT).

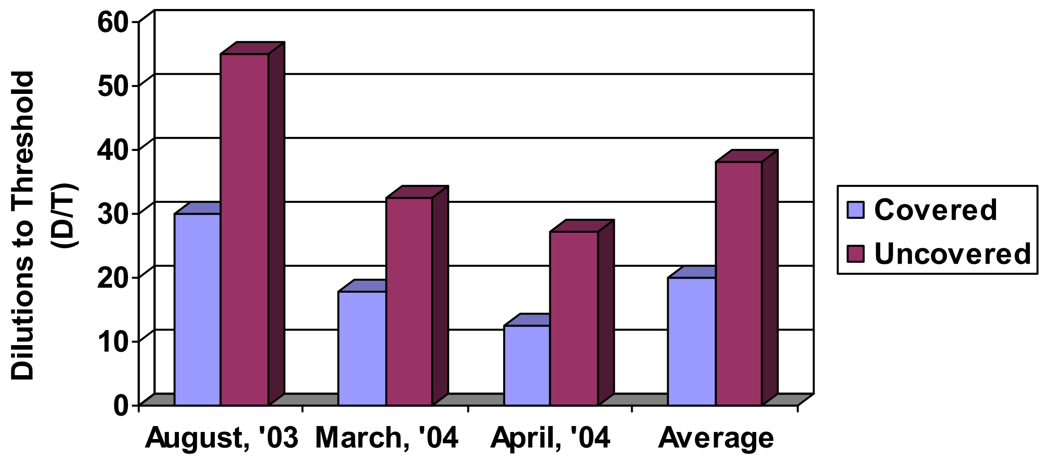

Figure 5. Regression Analysis of Detection Threshold, Ammonia and Hydrogen Sulfide Measured 200-meters Downwind of Dairy Odor Sources.