Comments Provided for Consideration to the SAB Animal Feeding Operations Emission Review Panel for the March 14-16, 2012 Meeting that will Review EPA's February 2012 draft reports: a) Development of Emissions Estimating Methodologies for Broiler Animal Feeding Operations; and b) Development of Emissions Estimating Methodologies for Lagoons and Basins at Swine and Dairy Animal Feeding Operations

Sally Shaver, Co-chair, AAQTF's Emissions Quantification, Mitigation, and Verification Subcommittee
Dr. Robert Burns, Co-chair, AAQTF's Emissions Quantification, Mitigation, and Verification Subcommittee

Submitted on behalf of members of the U.S. Department of Agriculture Agricultural Air Quality Task Force

March 7, 2012

Mr. Edward Hanlon
DFO, Animal Feeding Operations Emission Review Panel
Science Advisory Board
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue N.W.
Washington, D.C. 20004

RE: Materials for Consideration by the Animal Feeding Operations Emission Review Panel

The USDA Agricultural Air Quality Task Force (AAQTF) was established by Congress through Section 391 of the 1996 Federal Agriculture Improvement and Reform (FAIR) Act. Its purpose was to assist the Secretary of USDA in ensuring that scientifically valid information was used in determining the impact of agricultural sources on air quality. It is currently chaired by the Chief of the Natural Resources Conservation Service (NRCS), David White, and is composed of 26 members representing a broad spectrum of agricultural expertise, experience, and interest.

In September 2010, the AAQTF, NRCS, and the United States Environmental Protection Agency (EPA) sponsored a workshop on the standardization of emissions reporting for livestock and poultry operations. As a result of that workshop, three white papers were developed and subsequently finalized. These papers were written collaboratively by experts in the field.

The documents are:

> *Consistency in Mitigation Reporting AFO Air Emissions Practices* by Dr. Robert Burns, Dr. David Schmidt, Dr. Hongwei Xin, and Dr. Richard Gates.
>
> *Methodologies and Protocols for Analysis of Raw Data to Minimize Uncertainty of Resultant Aerial Emissions Estimation* by Dr. Hongwei Xin, Dr. Hong Li, Dr. Richard Gates, Dr. Robert Burns and Dr. Ken Casey.

Recommended Units and Supporting Data for Standardized Reporting of Air Emissions from Animal Agriculture by Dr. Eileen Wheeler, Dr. Deanne Meyer, Paul Martin, Dr. David Schmidt, and Dr. Wendy Powers with other contributing authors.

In its meeting on September 30, 2010, the AAQTF recommended to Chief White that:

> The AAQTF Livestock and Poultry Subcommittee and moderators (of the emissions standardization workshop) develop a 2-4 page summary to be included with the three white papers. The white papers should also be included in the minutes of the September 2010 AAQTF meeting, published as an American Society of Agricultural and Biological Engineers (ASABE) technical reference, and published through the Livestock and Poultry Environmental Learning Center. The development of a standardization framework proposal for future funding should also be supported.

The contents of these papers are pertinent to the deliberations of the Animal Feeding Operations Emission Review Panel that the Science Advisory Board has convened. The papers represent an effort to standardize data collection, analysis and reporting associated with quantification and mitigation of air emissions from animal agriculture, so that the resultant data can be more properly utilized for different purposes or applications. Particularly, the papers outline a) the needs and recommendations for different units in expressing air emissions to maximize the usefulness of the reported emission data; and b) some procedures to improve data analysis quality for complex measurement systems, and means to assess uncertainty of the reported emission values. Although not of direct relevance to the Review panel, the papers also recommend best practices in collection of raw data for baseline and mitigation assessment. Therefore, on behalf of the AAQTF, I wish to submit these papers to the panel for consideration as it deliberates the emission-estimating methodologies development for animal feeding operations. I further request that these be included on the Science Advisory Board website. Copies of these papers are attached.

Thank you for the opportunity to submit these comments to the Panel.

Sincerely,

Sally Shaver, Co-chair, AAQTF's Emissions Quantification, Mitigation, and Verification Subcommittee

Dr. Robert Burns, Co-chair, AAQTF's Emissions Quantification, Mitigation, and Verification Subcommittee

Attachments

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Consistency in Reporting AFO Air Emissions Mitigation Practices

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Abstract

The purpose of this document is to describe the need for consistency in how animal feeding operation (AFO) air emission mitigation system performance is reported, and to articulate the major underlying benefits and obstacles to such an approach. Specific objectives are:

a) To describe the need for consistency in reporting of both direct emissions and also as applied to analyses of mitigation technologies;

b) To articulate an example standardized reporting framework (SRF) that could be used as an initial draft to address these needs; and

c) To define the resources required to develop a standardized consistent framework for reporting on air emission mitigation system performance.

Introduction

Currently, systems for reducing emissions of air pollutants are being developed by research universities/institutes and private industry. However, the lack of standard protocols for quantifying and documenting the effectiveness of these mitigation systems is hindering the evaluation, adoption and further development of these technologies in the United States. In addition, the lack of standard quantification and reporting methods for air emission mitigation technologies makes it difficult for the regulatory community (local, state and federal) to confidently assign Best Management Practice (BMP) status to these technologies and for the agricultural community to confidently invest in these technologies.

Mitigation technologies can be generally categorized as pre- or post-generation. Pre-generation technologies include diet manipulation or methods to manipulate the emissions (e.g., temperature changes, chemical or biological additives). Pre-generation technologies may also be integrated into the facility design, e.g. building ventilation or manure handling systems. Post-generation include capture and treat technologies such as biological or chemical treatment on the building exhaust air or covers on manure storages. As such, methods of testing these technologies vary considerably, resulting in significant challenges when discussing standardized quantification and reporting methods.

Current Status of US Emission Mitigation Reporting

Comparison to control or comparison to baseline

Current status of US emission mitigation reporting is on an ad-hoc basis. In some systems, for example an air treatment system, measurements can be made upstream and downstream of a control device and thus the reduction in pollutant emission is directly determined and a statistical control is built-in to the evaluation. In other cases, for example when dietary manipulation is used, control diets and treatment diets must be administered to different groups of animals so that a control group can be compared to a treatment group. In addition to a statistical control, replication is critical so that statements regarding mitigation effectiveness can be made with a definable degree of confidence, preferably including statistical confidence. However when conducting full-scale field research on a technology the known variability from site to site makes finding representative "control" sites quite challenging.

Mitigation technology effectiveness can also be quantified in relation to baseline emission data. This baseline data would likely be some agreed upon emission value or emission factor for some specific type of facility or animal production type based on a review of emission rates reported in literature. However, this also can be very challenging as baseline data can be highly variable. For example, the mean ammonia broiler emissions reported from various US studies as discussed in Burns et al., 2007 range from 0.49 to 1.18 grams NH3 / bird-d. Similarly the European ammonia emissions data compared in Wheeler et al., 2006 range from 0.09 to 0.48 grams NH3 / bird-d. In addition, comparison of US to European data show generally lower emission values in the latter owing to use of new bedding after each flock and younger market bird age and thus lower body weights. Subsequently, this variability in baseline must be taken into consideration when comparing any mitigation measurements to any baseline values.

Measurement systems and sampling protocols

Most housing emissions studies in the U.S. have recently settled upon a fairly standard set of equipment and protocols. This has arisen in part from the Air Consent Agreement (ACA) between the USEPA and livestock and poultry groups. Researchers involved in these and related studies have developed a consistent set of techniques for most emitted constituents of interest (Burns et al., 2006, 2007c; Moody et al., 2006), and for the accurate determination of ventilation rates from buildings (Gates et al., 2004). However, the current US approach relies on long-term, high frequency sampling from a reduced sample of sites (e.g. three broiler houses in the entire U.S.) This strategy requires significant resources to collect an extensive amount of data on a rather limited number of farms. Consequently, variability among sites in terms of management, and facility characteristics are not being well quantified or represented under this approach.

A useful and cost-effective approach to sampling protocols utilizing less expensive monitoring equipment and frequent, limited duration visits to measure emissions has been developed in Europe (Mosquera-Lousada and Ogink, 2006; Vranken et al., 2004). This better captures variability within a farm over seasons and animal sizes, between farms on a similar day, and between farms over seasons. This sampling protocol is now the basis for performance evaluation of air mitigation systems in the Netherlands. The use of less expensive monitoring equipment (Gates et al., 2005) and a larger sample of houses was the strategy employed in the US baseline ammonia emissions studies documented by Wheeler et al. (2006) and Liang et al., (2005, 2006). A comparison between this and the more sophisticated system is an interesting analysis that should be conducted.

Of direct importance to AFO emissions mitigation is the long-term performance of a mitigation technology and the variability of this performance. Thus, while laboratory or field performance obtained from spot checks provides some indication of utility, longer-term assessment (either via semi-continuous measurements such as used in the ACA projects, or via multiple site visits over a representative time period as used in the Netherlands) should be the goal. Regardless of the sampling measurement system and sampling protocol used, it is critical to report factors that would impact the efficiency of a technology such as seasonality or as a function of building operation (e.g. ventilation rate, animal growth cycle).

Key Factors in Mitigation Testing and Reporting

While substantial recent progress is noted in determining baseline emissions for various US AFOs, substantial unknowns remain. This variation must be recognized, documented and reported for mitigation technologies. While some mitigation techniques may result in uniform reductions across temperatures, flocks, seasons, or ventilation rates, others may be quite dependent on these variables. As such, testing and reporting of mitigation efficiency must clearly report these testing parameters.

If mitigation efficiencies are reported in relationship to baseline data, the variation in this baseline data must also be considered in the analysis. For example, for the broiler emissions cited above, there is a strong linear correlation between daily emissions and bird age; the single average emission values reported in the previously mentioned studies (expressed on a per bird per day basis) completely miss this key factor. Burns et al (2007a) noted that emissions factors reported for broilers can be misleading, depending on market age, bird age when emissions were measured, and whether new litter was used. They reported (mean ± std. dev.) emissions of 12.4 ± 9.4 kg/d-house (new litter flocks), compared to 14.6 ± 9.0 kg/d-house (built-up litter flocks). Testing and reporting of a mitigation technology for broiler houses and reporting reductions based on comparisons to baseline must consider this variation.

Efficiency of a mitigation process is closely tied to the underlying physical units used to express the emissions. Conceptually, it is of interest to quantify mitigation performance in both relative and absolute terms. A common measure of relative efficiency is the reduction in pollutant stream divided by the pollutant flux upstream of the mitigation process. An example of an absolute measure of efficiency would be to report mass of pollutant mitigated. Generally, if the relative efficiency is obtained from representative operating conditions, it is a useful measure; of course, staging multiple mitigation processes does not mean that the relative efficiencies sum, unless the mitigation assessments were done at these differing loading rates.

The Principles 1 and 2 Whitepapers associated with this Whitepaper, list reporting units for emissions and the parameters that should be included in reporting any emission testing, including the reporting of results from mitigation technology testing. It is also likely that mitigation reporting would include percent reductions or mass reductions from baseline or from a control (i.e. pre and post treatment). This difference in reporting would be a function of the type of mitigation system tested and the testing method. Mitigation technologies that act on an air stream are conventionally characterized by metrics that include loading rate (of pollutant), residence time, and efficacy on a unit area or unit volume basis.

The cost of mitigation is a key factor in successful adoption. For example, a lower cost and low management system, with lower mitigation efficiency, may be superior to a high efficiency system if wider adoption and regional impacts are desired. Conversely, in a nuisance situation it may be preferable to employ a high efficiency and higher cost method to directly address the problem.

How to quantify cost of mitigation needs to be better resolved. Typical approaches currently used are to express the investment and operating costs on a per volume of air treated, on a per animal basis, or on a per unit area of building or mitigation material. When reporting mitigation costs, it is necessary to fully specify a system's operational conditions so that meaningful comparisons to other systems can be made.

Standard Reporting Framework

Several models exists for standardized reporting and or certification of emission factors. There are multiple national and international organizations involved in assigning GHG emissions for the purpose assigning carbon credits. These organizations have developed specific protocols for quantification, validation, verification, monitoring and reporting of green house gas emission removals or reductions (Credit Certification. Retrieved 9/20/2010, from http://www.suite101.com/content/carbon-credit-certification-a99865). A similar type of system could be employed for assigning and verifying AFO mitigation technologies.

Other options include performance testing and certification through an organization such as the USEPA's Environmental Verification Testing Program or simply a standard method of reporting the results from any mitigation system testing. The development and implementation of a recognized SRF would require significant effort and coordination from a variety of interest groups. However, to help illustrate the concept, a draft of such a Standardized Reporting Framework (SRF) is described below. In general, any SRF would likely include a summary of the mode of action for the mitigation technology, specific details of the experimental design and testing and reporting of the raw data along with a clear statistical analysis and summary of the results.

Draft Standardized Reporting Framework Example

- ***General Information, Mode of Action, and Cost Estimation***
    - *Company, Technology Name, Primary Contact, Address, Phone/fax/email,*
    - *Make and model of equipment used in the testing*
    - *Description of the mode of mitigation and any unintended consequences of the technology (e.g. technology may reduce ammonia emissions but will increase hydrogen sulfide emissions because of pH shift)*
    - *Anticipated capital and operational cost per unit (kg or pound) of pollutant reduction or per treatment unit (i.e. per barn, animal space, ventilation volume, etc.)*

- ***Experimental Design and Testing***
    - *Testing Hypothesis*
    - *Detailed description of sample collection method*

        - *e.g. monthly 24-hour monitoring with measurements taken hourly*
        - *e.g. # sampling periods*
        - *e.g. sample collection at exhaust fans from building*
    - *General information describing the field sites where the mitigation technology was tested. If the technology was tested in the laboratory or using a pilot scale system details of the system should be provided.*

- ***Raw Data Reporting***
    - *Date and times of sample collection*
    - *Status of source (as outlined in Principles 1 and 2) and including*
        - *number and weight of animals*
        - *Notation of system changes, breakdowns or modifications within previous 30 days*
        - *Recent maintenance of the system or system status at the time of sampling*
        - *Environmental conditions such as temperature, wind speed, etc. at the time of sampling*
    - *Data necessary for calculations of Emission Rates (Principle 1 and 2)*
        - *Concentrations of the pollutants*
        - *Flow or ventilation rate measurements during reported concentrations*

- ***Statistical Analysis***
    - *Estimated emissions or emission reductions reported in the primary measurement units. Note if emissions or emission reductions are a function of season, or source operating parameter these variations should be noted (e.g. XX g/s during minimum ventilation conditions and YY g/s during maximum ventilation conditions)*
    - *Statistical variation for each of the emission or emission reductions reported.*

Resources Required to Develop a Standardized Reporting Framework

The need to standardize reporting performance on AFO air emissions mitigation practices has been recognized by researchers, regulators and animal producers in the United States. (Schmidt et al., 2008). However, no mechanism to organize and fund such an effort in the US has been clearly identified to date. In order for a formal, standardized framework for reporting on AFO Air Emissions Mitigation Practices to become a reality in the United States, both an organizational leadership infrastructure and a funding mechanism need to be identified and or developed to support this task. Specifically we envision that the order of action items that would result in the development of a standardized US reporting framework for AFO air emissions mitigation practices with broad buy-in and support from researchers, regulators and producers would be as follows;

1) Identify and assemble a core group of individuals committed to lead the effort
2) Seek initial guidance and input from all interested stakeholders
3) Identify / develop an organizational structure to work within

4) Develop a timeline to develop the Standardized Reporting Framework (SRF)
5) Acquire funding to support the development of the SRF
6) Draft the initial SRF guideline document
7) Utilize stakeholder focus groups to review and provide input on the draft SRF
8) Finalize the SRF and distribute for use

Potential organizational structures that could be used to develop the proposed Standardized Reporting Framework include; 1) professional societies such as the American Society of Agricultural and Biological Engineers (ASABE) or the Air and Waste Management Association (AWMA), 2) USDA based national or regional collaborative research and extension groups such as S-1025 or Southern Extension and Research Activity groups, 3) integrated teams funded by competitive sources such as AFRI grant projects, or 4) collaborative teams where each team members participation is funded by his or her employer. Each of these potential organizational structures has various pros and cons that must be considered. Similarly, some funding models work better within some organizational models than others. The primary goal would be to select an organizational and funding model that would best facilitate the development of a Standardized Reporting Framework that is practical, broadly supported by stakeholders and delivered in a reasonable timeframe.

Summary

We believe that planned deliverables from the AAQTF September 27-28, 2010 Air Emissions Standardization workshop should include the two first action items identified in this white paper. Specifically, the identification of a core team of individuals committed to lead the development of a US Standardized AFO Emissions Mitigation Standardized Reporting Framework, and the collection of guidance and input from interested stakeholders should be completed at the AAQTF September 27-28, 2010 meeting if at all possible.

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Methodologies and Protocols for Analysis of Raw Data to Minimize Uncertainty of Resultant Aerial Emissions Estimation

A White Paper Prepared on Behalf of the AAQTF Livestock and Poultry Subcommittee

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Purpose and Objectives

This document is a part of the guidance references that outline and define the appropriate data collection, emissions estimating methodologies and reporting procedures for air emissions and mitigation practices at livestock and poultry operations. The purpose of this document is to describe procedures and techniques for processing emissions-related raw data that will lead to reduced uncertainty of resultant emissions data. The two companion documents are "*Standardized Reporting of Gas Emissions from Animal Agriculture*" and "*Consistency in Reporting AFO Air Emissions Mitigation Practices*".

Specific objectives of this document are:

a) To describe procedures and protocols for determining instantaneous and daily emissions of the source based on recorded measurement readings, i.e., collected raw data;
b) To describe ways for providing backup or check of source ventilation rate to enhance data quality on resultant emissions; and
c) To illustrate the procedure of assessing emissions uncertainty through error analysis.

Governing Equations of Aerial Emissions Determination

Emission rate (ER) of aerial constituents from a source (e.g., an animal house) is determined by one of the following equations:

$$[ER_G]_t = \sum_{e=1}^{n}[Q_e]_t\left([G]_e - \frac{\rho_e}{\rho_i}[G]_i\right)\times 10^{-6}\times\frac{w_m}{V_m}\times\frac{T_{std}}{T_a}\times\frac{P_a}{P_{std}} \qquad [1]$$

$$[ER_{PM}]_t = \sum_{e=1}^{n}[Q_e]_t\left([PM]_e - \frac{\rho_e}{\rho_i}[PM]_i\right)\times 10^{-6}\times\frac{T_{std}}{T_a}\times\frac{P_a}{P_{std}} \qquad [2]$$

where $[ER_G]_t$ = Gaseous ER of the source during sample integration time t, (g house^{-1} t^{-1})
$[ER_{PM}]_t$ = PM emission rate of the house (g house^{-1} t^{-1})
$[Q_e]_t$ = Average ventilation rate of the house during sample integration time t under field temperature and barometric pressure (m^3 house^{-1} t^{-1})
$[G]_i$,$[G]_e$ = Gaseous concentration of incoming and exhaust ventilation air, ppm$_v$
$[PM]_i$ = PM concentration of incoming ventilation air (ug m^{-3})
$[PM]_e$ = PM concentration of exhaust ventilation air (ug m^{-3})
w_m = molar weight of air pollutants, g mole^{-1}
V_m = molar volume of the gas under consideration at standard temperature (0°C or 20°C) and pressure (1 atmosphere) (STP), 0.022414 m^3 mole^{-1} (0°C) or 0.024055 m^3 mole^{-1} (20°C)
T_{std} = standard temperature, 273.15 K (or 293.15 K)
T_a = absolute house temperature, (°C+273.15) or (°C+293.15) K
P_{std} = standard barometric pressure, 101.325 kPa

P_a = atmospheric barometric pressure for the site elevation, kPa
ρ_i, ρ_e = air density of incoming and exhaust air, kg dry air m^{-3} moist air

The following sections describe the procedures and protocols for raw data analysis that aim to reduce uncertainty of the resultant emissions data.

1) Determination of Source ER from Multiple-Location Measurements

In monitoring air emissions from animal facilities, it is typical that one set of instruments are used to take measurements from multiple locations within one or more animal facilities to cover the spatial variations in constituent concentrations. Such arrangements necessitate sequential sampling of the measured locations. For instance, one gas analyzer is used to sequentially measure ammonia concentrations from three locations of an east-west oriented, mechanically-ventilated animal barn – east, middle and west locations. The analyzer is set to complete one measurement cycle in 30 seconds. Let's say that air at each location is sampled for 2 minutes, with the last 30-s readings (i.e., the 4th measurement cycle) taken as the "true" or equilibrium concentration reading of the location (note that the number of measurement cycles taken to reach equilibrium can vary considerably, depending on the response time of the analyzer involved). Hence it would take 6 minutes to complete one sampling cycle for the example animal barn. In the meantime, instantaneous readings of the operational time of the ventilation fans and building static pressure, hence barn ventilation rate (VR), are logged at 1-s intervals (this small time step is used to maximize the accuracy of measuring fan on-off status, hence running time). To obtain 1-s instantaneous concentrations between the two 6-min interval concentration readings, interpolation can be used for each location. With the 1-s instantaneous concentration and the corresponding VR data, resultant 1-s ERs can be calculated using equation [1] (for gases) or [2] (for PM). Summation of the instantaneous emissions over one-hour yields hourly emission of the constituent; and similarly summation of the instantaneous emissions over one-day period yields daily emission of the constituent.

2) Determination of Daily Emissions of a Constituent from Instantaneous ERs vs. from Daily Mean Concentration and Daily Mean VR

When certain concentration measurement techniques are involved, such as washing of exhaust air ammonia through acidic solution or use of gravimetric PM filter over extended period of time, instantaneous readings of the gaseous or PM concentrations would not be practical. Instead, daily mean concentrations are attainable. The question is "*Can one use the daily mean concentration and the corresponding daily mean VR of the house or source to determine daily emission?*" The answer is it depends. One can do so without biasing the data if one of the following situations holds true: a) concentration of the constituent remains relatively constant throughout the day, or b) VR of the house remains constant throughout the day. Situation b) can happen under warm climatic conditions where all house ventilation fans remain operating throughout the day. However, if neither condition holds true, errors will likely result from use of daily mean concentration and daily mean VR to compute daily emission. An example illustrating the situation with a laying-hen house is given in figure 1, where ER (62 g/min) derived from use of daily mean VR and mean concentration was 25% higher than that (50 g/min, more realistic) determined from dynamic ERs throughout the day.

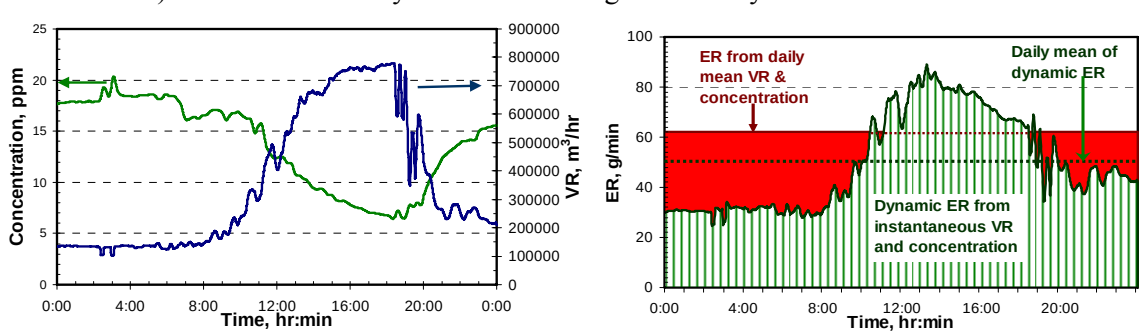

Figure 1. Comparison of ERs derived from instantaneous VR and concentration (50 g/min) and daily mean of VR and concentration (62 g/min) from a laying-hen barn.

3) Determination of Daily and Cumulative Emissions per Animal or Per Animal Marketed

For animals whose body weight and feed intake remain relatively constant, e.g., dairy cows and laying hens, daily emissions per animal or per animal unit (500 kg live body weight) provide a good measure of the emission magnitude. However, for animals whose body weight and feed intake keep changing throughout the production stage, e.g., meat-type birds (broilers and turkeys), pullets (young hens before start of lay), and grow-finish pigs, daily emission per animal has little meaning in assessing the emission magnitude. In such dynamic cases, emissions per animal or animal unit (500 kg live body weight) *marketed* would be more meaningful. To obtain emissions per animal marketed at certain age, one may follow the steps below:

a) Calculation of daily emission for the source (e.g., animal house) using the procedures described above;

b) Calculation of cumulative emissions of the source up to the particular date of interest (i.e., animal market age); and

c) Divide the number of animals existing in the house for the specific day into the cumulative emission up to the current animal age. The existing number of animals would have taken the cumulative animal mortality into consideration. The resultant emission value is the cumulative emission corresponding to the animal age. Table 1 shows an example of cumulative ammonia emissions per broiler marketed at different ages.

Table 1. Ammonia emission rates reported as lb/house and g/bird marketed

Bird Age, d	Bird Population	Daily ER, lb/barn-d	Cumulative ER, lb/barn	Cumulative ER, g/bird marketed
1	25695	0.73	0.73	0.01
2	25680	0.93	1.67	0.03
3	25665	1.03	2.69	0.05
4	25646	1.12	3.82	0.07
5	25635	1.36	5.17	0.09
6	25622	1.17	6.34	0.11
7	25610	0.86	7.20	0.13
8	25596	1.20	8.39	0.15
9	25587	2.25	10.6	0.19
10	25578	4.41	15.1	0.27
11	25561	5.18	20.2	0.36
12	25550	6.26	26.5	0.47
13	25540	6.76	33.3	0.59
14	25523	5.31	38.6	0.69
15	25509	7.38	45.9	0.82
16	25499	8.11	54.1	0.96
17	25486	12.5	66.6	1.18
18	25472	18.8	85.3	1.52
19	25449	22.5	107.8	1.92
20	25433	22.7	130.6	2.33
21	25417	23.8	154.4	2.75

For different units of reporting aerial emissions, one can refer to the companion paper on *"Standardized Reporting of Gas Emissions from Animal Agriculture"*.

4) Handling of Missing Within-the-Day Concentration Data and Daily Emission Data

Missing concentration data within the day can occur due to instrument malfunction, scheduled instrument checking and calibration, as needed. When this happens and the available concentration data seem to follow certain pattern, regression equations maybe developed using the available data surrounding the gap to fill the missing data through interpolation. If such regression interpolation is not possible but the amount of available data meet the data quality objective (Moody et al., 2008), say, 75% data completeness, time-weighted average, as opposed to arithmetic average, of the different time periods (e.g., dark vs. light) should be used to estimate daily emission. Use of time weighted instead of arithmetic mean is due to the fact that emissions during light vs. dark hours likely differ and the number of light vs. dark hours in the day is generally uneven in animal housing. Missing daily emission data may be filled through regression interpolation as well.

5) Use of CO_2 Balance for Indirect Estimation of VR

Whenever possible, use of CO_2 balance to indirectly estimate VR of the animal barn should be considered. The indirectly determined VR serves as a backup or check of directly measured VR. Extended operation of ventilation fans will lead to degradation of their performance due to dust accumulation on the blades and shutter, loose belt, motor wear, etc (Casey et al, 2008; Person et al., 1979). Hence, fan performance curves obtained from *in-situ* calibration are subject to change over time. Comparison of the directly vs. indirectly determined VR may provide an assessment of the degree of fan curve drift and possible corrective adjustment. It should be noted that for the CO_2 balance method to work properly, it is essential to have accurate data on metabolic heat production of the animals and good estimation of appreciable CO_2 production from other sources (e.g., manure decomposition). Advancement has been made in updating or quantification of metabolic heat production (HP) for modern animals (Xin et al., 1996; 2001; Chepete and Xin 2004; Chepete et al, 2004; CIGR, 2002; Green and Xin, 2009). Li et al. (2005) and Xin et al. (2009) have demonstrated the feasibility of using CO_2 balance to estimate VR of poultry houses. The studies showed that certain time interval of integration (e.g., 1 hr or greater) is needed for the CO_2 balance method to work properly because the HP data are generally hourly mean values which do not adequately reflect ventilation dynamics in smaller time intervals. It should also be noted that CO_2 balance may not work well when difference in the gas concentrations between exhaust and incoming air streams is less than 200 PPM, which may happen during maximum summertime ventilation.

6) Use of Mass Balance to Estimate Emissions or Check Data Quality

In cases where measurements of dynamic emissions are impractical, e.g., with naturally-ventilated animal houses, mass balance (of nitrogen, carbon or water) over a certain time period can provide a means to estimate overall emissions during the covered time period. By the nature of emissions estimated over a relatively extended time period (e.g., days, weeks or months), the mass balance-derived values cannot delineate daily maximum emissions or circadian patterns. Mass balance can also provide a useful check of the overall data certainty and its use is encouraged when possible. For instance, nitrogen (N) mass balance has been used to compare ammonia emissions determined from measurements of concentration and building VR (referred to as flow integration method) for high-rise laying-hen houses (Liang et al., 2005), and the annual ammonia-N loss by both methods agreed well. In other cases, such as meat-type birds (broilers and turkeys) raised on litter, N loss from mass balance would likely be considerably higher than ammonia-N loss as obtained through flow integration method (Li et al., 2010). This considerable difference stems from additional (substantial) N loss in other forms, particularly N_2 gas, for the litter bedding system. Hence, if ammonia-N loss derived from the flow integration method is greater than that from mass balance, one should become concerned about the quality of the data. In both cases of mass balance application, proper record-keeping of nutrient input and output (including animal protein and manure mass) is absolutely essential to ensuring the data quality of mass balance calculation.

7) Presentation of Gaseous Emissions Obtained with Dynamic Flux Chambers

Dynamic flux chambers (DFCs) have been used to quantify gaseous emissions from animal manure/litter or feedlot operation (i.e., naturally ventilated facilities) where quantification of VR is formidable. Gaseous emission rates measured with DFC can be greatly affected by air exchange rate through the DFC which presumably affects the boundary layer condition of the emitting source. Figure 2 demonstrates how NH_3 and CO_2 emissions from laying-hen manure are affected by air exchange rate of a DFC unit (Acevedo et al., 2010). In the real-world situations, air exchange rate or boundary layer conditions of the emitting sources are subject to influence of climatic conditions and animal activities. Yet no standards exist in terms of air exchange rate to be used in such measurements, making it difficult to compare results from different studies. Hence, it is recommended that air flow rate(s) through the DFC be specified when reporting emissions data obtained with this method. Discussion among researchers should be initiated about use of certain standardized air exchange rate (ACH) or a range of ACH when conducting/reporting emissions measurements with DFCs. Although the DFC-based emission values may still not reflect the actual emission situation, at least data from different studies share some common ground for comparison.

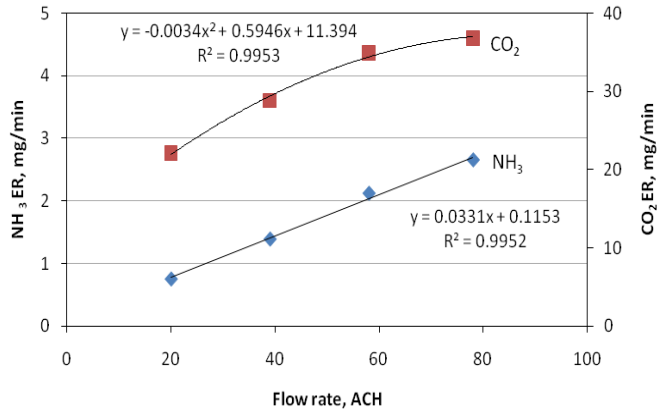

Figure 2. Ammonia (NH_3) and carbon dioxide (CO_2) emission rate (ER, mg/min) of laying-hen manure measured with a dynamic flux chamber at different air exchange rates (expressed in air changes per hour or ACH) *(Source: Acevedo et al., 2010).*

8) Uncertainty of Component Measurements and Resultant Emission Estimation

Definitions of accuracy, precision, bias, uncertainty, and error abound in the literature (e.g., Doeblin, 1990; Taylor and Kuyatt, 1994; ISO/IEC, 2008; NIST, 2009). Fundamentally, accuracy is how well a measurement matches the "true" value (which may, or may not, be known). "Error" is considered a subjective term and is generally comprised of random and systematic components. The random component is the precision, and when quantified is called uncertainty. It represents repeatability in measurement. The systematic component may be removed by calibration, or accounted for using a component error analysis method as described below, in which case it is also part of the overall uncertainty. The term "uncertainty" is used when the estimate of error has been quantified; thus, the term "error" is generally qualitative and "uncertainty" is quantitative (ISO/IEC, 2008; Taylor and Kuyatt, 1994).

Air emissions are actually not measured, instead they are computed. To compute ER over a time interval, several measurements are needed, as shown in Equations 1 and 2. For a 3-zone broiler house such as described in Section 1, there are three emission points and thus 17 different measurements, plus fan activity status for up to 14 fans, for a total of 31 different dynamic measurements. In addition to these direct measurements, VR of each operating fan is computed from the building static pressure and a fan performance curve obtained as part of a calibration procedure. Thus, “measuring” building ER actually constitutes its calculation from numerous independent measurements, and each of these measurements includes a degree of error since no measurement can be perfect. Each of these measurement errors combines, or propagates forward, into computation of the building ER; and ignoring these errors provides false confidence on ER accuracy. Quantifying these errors should be a key part of any emissions study.

A commonly employed means of quantifying error in a measurement is to assess the uncertainty. It is preferable to provide a statistical basis for a measurement’s uncertainty, based on instrument manufacturers’ specifications or laboratory calibration and assessment. These measurement uncertainties take on the form of a standard deviation, and hence are typically called “*standard uncertainties*” (ISO/IEC 2008). These measurement standard uncertainties (Δ’s) are propagated into the computed ER

(eq. 1 or 2) according to component error analysis (ISO/IEC 2008, Taylor and Kuyatt, 1994). This in turn provides an estimate of ER variance (ΔER^2) or standard deviation (ΔER). With estimates of ER variance, one may assess and quantify the degree of confidence assigned to building emissions, and construct confidence intervals or related accuracy statements (Gates et al, 2009). For example, if ΔER follows a normal probability distribution, $\pm 2\ \Delta ER$ is equivalent to approximately 95% of expected variation in a computed ER.

Gates et al. (2009) evaluated the combined standard uncertainty in ER from a broiler emissions monitoring project that was part of the national Air Consent Agreement studies. The analysis consisted of "typical" (Case 1) and "worst-case" (Case 2) scenarios to determine the relative contribution of component uncertainties to ΔER. For the concentration measuring equipment with high accuracy, it was shown that VR uncertainty typically accounted for over 90% of ΔER. Figure 3 (adopted from Gates et al., 2009) shows that $\Delta ER/ER$ is greatest at lower VR and at greater VR uncertainty. It is quite challenging to hold VR uncertainty below 10% even when careful procedures and in-situ calibration of each fan (Gates et al., 2004, 2005) are involved. In fact, it is not uncommon for VR uncertainty to exceed 25%. When it happens, concentration measurement uncertainty of 0.5% vs. 5% makes rather small difference to the ER uncertainty (11% vs. 14% in this example).

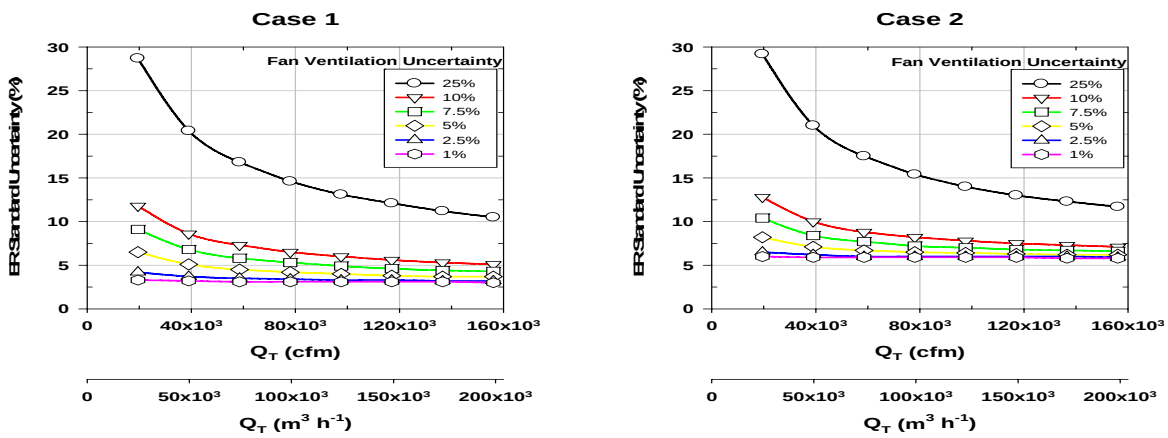

Figure 3. Combined standard uncertainty estimates for ER as a function of building ventilation rate (Q_T) and ventilation uncertainty (ΔQ_T) expressed as % of Q_T. Note that each point along a curve represents one more fan with the same uncertainty being added. Case 1 uncertainties on inputs include 3% for calibration gas and 0.5% instrument standard uncertainty; whereas Case 2 uncertainties on inputs include 3% for calibration gas and 5% for instrument standard uncertainty. *(Source: Gates et al., 2009).*

9) Continuous vs. Strategic Periodic Measurements

Continuous (i.e., 24/7) monitoring of air emissions over extended period of time (e.g., one year) to cover seasonal effects requires great deal of time and resources. As such, it severely limits the number of animal facilities that can be monitored, hence representativeness of the resultant data. Seemingly identical animal facilities can differ considerably in the magnitude of air emissions, depending on how they are managed; let alone the variations in climatic conditions and different housing characteristics throughout various geographical locations. Naturally, periodic measurement strategies that greatly reduce the resource and time requirements while yielding comparable estimation of emissions from a larger number of farms, hence greater statistical power, are of scientific and economic values. Although information is not as abundant yet in the literature, some recent work has been conducted to assess the effects of strategic, intermittent measurements on estimation of annual air emissions from animal facilities. Specifically, Vranken et al. (2004) developed a method for predicting annual ammonia emissions based on a statistical model, derived from 345 days of emission measurements on a commercial Belgian pig farm. The model related intermittent measurements of ammonia emission to building VR and animal body weight. The authors reported that strategic sampling of eight days in the year was sufficient to model the relationship between ammonia emission vs. VR and average pig weight, thereby predicting annual ammonia emissions from Belgian pig houses. Liang et al. (2006) evaluated effects of bi-weekly, tri-weekly,

monthly, or bi-monthly 24-hr sampling on estimation of daily maximum and annual ammonia emissions of high-rise laying-hen houses in Iowa, USA, as compared with weekly, 48-hr sampling. The authors concluded that ammonia emissions from the high-rise houses based on 24-hr, bi-weekly sampling would yield a ±10% uncertainty in annual emissions as compared to weekly, 48-hr sampling. At the same time, the less frequent measurements would introduce much larger uncertainties (46%-73%) on maximum daily emissions. Mosquera and Ogink (2006) reported that determination of ammonia emissions from animal production in the Netherlands for estimation of emission factors or mitigation efficacy would use intermittent, as opposed to continuous, sampling at an increased number of animal farms to increase data representativeness. A similar approach was used in an earlier multi-state study of ammonia emissions from broiler and laying-hen houses in the United States (Liang et al., 2005; Wheeler et al., 2006).

Hence, it seems that potentials exist to reduce measurement frequency and improve measurement economics while still yielding comparable results in annual emission estimation. However, one needs to exercise caution when dealing with different purposes of the data (e.g., daily maximum value vs. annual emissions). More work is warranted in this area.

Summary

This document is developed to provide some guidelines on data analysis methodologies that will reduce uncertainty of air emission values computed from the corresponding raw data. The highlights are recapped as following:

a. Dynamic (e.g., 1-s) concentrations between two measured values over a time (e.g., 6-min) interval may be obtained through regression interpolation. The dynamic concentration together with the corresponding ventilation rate (VR) will yield the dynamic emission rate (ER). Summation of dynamic emissions over the day yields daily air emissions.
b. Care needs to be taken when using daily mean concentration and mean VR to determine daily emissions. The method is valid when one or both of the two variables (VR or concentration) remain relatively constant throughout the day.
c. When dealing with animals of highly variable body weight (e.g., meat-type animals), use of cumulative emissions per animal or animal unit (500 kg body weight) marketed is more adequate than daily emissions per animal or AU.
d. Time-weighted average, as opposed to arithmetic mean, should be used when estimating daily emissions where there are missing hourly ER data and there exist circadian patterns in the emissions.
e. Indirect determination of VR through CO_2 balance can provide a useful backup or check for directly determined building VR, and its use is encouraged when possible. Metabolic heat production data reflecting the current animal genetics, nutrition and environment are essential to the success of the method. The method may not work well when difference in CO_2 concentration between the exhaust and incoming air streams is less than 200 PPM.
f. Mass balance should be considered and included, when possible, as a check to emission values obtained from flow integration method.
g. When presenting air emissions obtained with dynamic flux chambers, air exchange rate(s) (expressed in air changes per hour or ACH) through the flux chambers should be specified.
h. Uncertainty of an emission value should be estimated through error analysis and provided when reporting emissions. A recently completed broiler emissions monitoring study demonstrates that unless VR uncertainty can be controlled below 10%, concentration uncertainty of 0.5% vs. 5% makes little difference in the resultant emission rate uncertainty.
i. Strategic, intermittent sampling, as opposed to continuous monitoring, coupled with statistical modeling may provide viable means to significantly reduce time and resource requirements for estimating annual emissions. Such approach would increase the ability to sample more farms, which in turn enhances representativeness of the data.

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Recommended Units and Supporting Data for Standardized Reporting of Air Emissions from Animal Agriculture

White Paper USDA NRCS Agricultural Air Quality Task Force
21 September 2010 Livestock and Poultry Sub-Committee

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Purpose of this document is to provide guidance for presentation of emission data from on-farm evaluations so that comparisons among animal farms and mitigation strategies can be universally compared. Specifically, this document provides 1) Recommended units for reporting emissions to best represent an end use for the information; and 2) Outlines collection of raw data related to physical, biological and operational characteristics of the enterprise that are needed for the development of the emissions in the recommended units. There is a need for Standardized Reporting as emission unit expressions vary widely, often do not note the uncertainty in the measurements, and typically do not fully characterize the conditions under which the data were collected. The document offers examples of emission expressions and units that offer insight into the wide variety of circumstances contributing to air emissions on poultry (broiler meat and egg layer), dairy, and livestock (swine, beef) animal farms.

Recommended Units

Below are four major uses of standardized emissions reporting. Different emission reporting units and supporting data are often required for each use as described below.

A. Regulations: air pollution

B. Modeling: process-based and dispersion

C. Life Cycle Analysis and efficiency: carbon credits; carbon taxation; “greenest” production methods

D. Public Information

A. Regulations

Air pollution regulations require estimating emissions and reporting. A value is applied to the population (count or size) to sum total emissions. In many cases the traditional reporting units for farm emissions are based upon the number of animals contributing the emissions or some average weight of all the animals contributing to the emissions. **The problem that needs resolution is that for certain sources at a farm a "per animal" expression of emissions does not address the specific unit that creates the emissions.** Also, the calculations performed to create a traditional "per animal" reporting of emissions include additional error, as actual animal weights and numbers are often variable and are not usually measured as precisely as are some other source parameters. This can lead to a profound disconnect between emissions and the actual point at which effective controls can be initiated.

Emissions are best expressed in units based on opportunities for control measures. Units of mass per head are appropriate when the control measure is the animal (reduction of animals or modification of animals to yield emission reductions). Units of mass per square foot of surface area are appropriate when the control measure(s) modify the surface area (e.g., reduction of disturbed silage surface, modifying husbandry practices to alter corral moisture content). Units of mass per potentially volatile solid fraction (mass) are appropriate when the control measure(s) modify the volatile fraction (e.g., nitrogen or starch reduction).

Different emission expressions are used to represent variation among emission sources on an animal farm. When animal populations are stable and well characterized [e.g. mature stock with predictable nutrient intake and, therefore, excretion: layer hens;] emissions may be expressed per animal or body weight measure, i.e. emission rate [ER]/ cow or more universally ER/Animal Unit [AU] where AU is defined as 500 kg of body mass. Growing animals [broiler, pigs] are more difficult to document due to the changes in body mass over time, i.e. ER/average bird weight, and have to be carefully analyzed. Area based emissions as ER/m^2 from the emitting source area, i.e. exposed and disturbed surface of a silage pile, are most appropriate for stored materials [manure pile, silage bunker, compost piles, or feed bags] and other open areas [feedlot, exercise yard, exposed liquid manure storage].

Emissions expressed as a per animal emission factor (i.e. mass/head/day or mass/AU/year) are useful for establishing a region wide inventory or to set permitting thresholds. But for other regulatory uses, such as analyzing peak emissions from an area source and the associated duration of those emissions, mass/area/time is more appropriate. To evaluate mitigation measures to determine control efficiencies units of either average mass per animal per unit time or mass per area per time may be used but, must be related to the actual substrate of the emission source (or critical control point).

B. Modeling

Of prime importance is expressing emissions in terms of the "unit that is causing them." Particularly for process-based modeling efforts, emission discovery often requires collection of chemical composition and conditions of emitting sources, such as manure and stored feed, in addition to more easily obtained knowledge of the animal population on the farm. Sometimes the seemingly easiest emission expression, for example "pounds of ammonia emission per bird per day", has no relationship to the actual emission source, which is the excreted manure not the bird itself. So with a goal of emission reduction, in this example, then the obvious solution is to

reduce the number of birds, but this does not necessarily reduce the exposed surface area of manure in the barn or emissions if chemical and biological activity within the manure subsequently enhanced ammonia emission. Emission from stored materials needs to recognize that ER/animal is not as useful as ER/ unit-feed (or constituent)-fed, or ER/ft^2 of laid out feed, or ER/ft^2 of disturbed feed bunker face. The nutrients excreted from an animal are directly related to what was fed. In order to provide the data necessary to develop and run a process-based model one must identify the biological processes that occur in the subject organism and report emissions on an elemental basis. For dispersion modeling the focus is on the open source area (or volume) for estimating emission rate at the source based on data collected downwind.

C. Life Cycle Analysis (LCA)

Productivity of modern animal agriculture is addressed in emission units by association with the final product produced (ER/gal. milk). This approach also allows comparison of animal production methods for determining the "greenest" method including life cycle analysis of products. Diet has a big impact so dietary input is essential to understanding productivity gains in relation to emission reductions. The intended direction is to carefully characterize production, for example, so that the final product of high-producing Holstein dairy cows does not overshadow the different food product goals of smaller Jersey dairy cows with highly marketable milk-cream content. Emissions on a per unit of production (e.g. per dozen eggs, gallon of milk, lb of meat, animal marketed) are the appropriate reporting terms when performing an LCA. Emissions should be related back to the ultimate reason for farm animal production in the first place – which is to provide food for the human populace. Therefore, efficiency of production becomes the most important factor to review as production systems and performance are compared. However, for analyzing reduction of emissions, other methods of expression may work better. A LCA-type comparison may be useful for criteria pollutants and the associated permitting considerations.

D. Public Information

Emission data from animal facilities tend to be very specific to the conditions under which they were collected. Data are often non-transferable region-to-region of the country due to differences in diets fed (Midwestern corn based dairy cow diet versus California by-product, low-starch feed ingredients). It is established that diet composition can significantly affect some air emissions (e. g. protein content is positively linked to ammonia emission). More importantly, data do not necessarily scale based on animal body weight. This is particularly true when comparing across breeds (large Holstein versus smaller Jersey dairy cattle or cattle for beef versus for milk) and even worse across species (six 200-pound hogs is not the emission equivalent of one 1200-pound dairy cow). A few emission-related definitions are provided for clarification at the end of this document that should be particularly helpful in dissemination of public information.

The public is interested in having emissions expressed in variety of ways, depending on the circumstances involved. Many individuals are concerned about air quality "hot spots," especially for such emissions as ammonia, dust (particulate matter, PM), and odors. In this case, they will be looking at emissions from a whole farm standpoint. The traditional "per animal" reporting may be appropriate for PM calculation purposes since much of the PM is due to animal activity, but would not be appropriate for ammonia or odor as it would focus the control point incorrectly on the number of animals rather than the unit which creates the emissions of concern

(related to manure moisture, pH, volatile nutrients, etc.). Other individuals may be more interested in regional issues, such as ozone precursors or greenhouse gases, where reporting as a function of production can be considered more appropriate.

Primary and secondary units

Emission unit is influenced by the type of facility and final use of the data as already described. *Primary* emission units are directly from the measurements on-farm with *secondary* units available based on parameters collected to allow conversion from one emission expression to another. The uncertainty associated with the measurements needs to be reported (see companion NRCS White Paper "Methodologies and Protocols for Analysis of Raw Data to Minimize Uncertainty of Resultant Emissions Estimation" for details of uncertainty analysis and expression). The following are five potential expressions of Emission Rate (ER), defined as contaminant mass per unit time for types of source. Some examples are provided of situations in which they are most useful.

1. Per Farm (e.g. ER/500-cow-dairy); Not commonly used due to complexity of accounting for all emission sources under various management options, weather, and geographical differences.
2. Per Unit of Area (e.g. ER/m^2) for animal housing, open lots, manure storage, and feed storage; most common for emissions that do not originate from a fully enclosed building.
3. Per Occupant (e.g. ER/bird) for animal, place (i.e. # stalls), body weight, productive animal ["per milking cow" = lactating/dry cow + her replacements]; Very commonly used for enclosed buildings or where the animal population is relatively stable in both number and body weight.
4. Per Unit of Food Product (e.g ER/lb pork, gallon of milk, dozen eggs, or weaned piglet) for final food product or animals marketed; Increasing in use as animal agriculture has become more efficient in product produced with reduced animal population.
5. Per Inputs (e.g. ER/kg nitrogen fed). Best use in models and pollutant mitigation where the biological, chemical, and management influences can be fairly evaluated.

Data Collection

Data obtained during on-farm air emissions monitoring of animal enterprises (dairy, poultry, and livestock) includes biological, physical, chemical, and operational features in order to fully characterize the facility, management influences on emissions, and the emission pattern. There is tremendous variability in inputs to biological systems on-farm and their resulting outputs compared to more commonly measured emissions from industrial sources where the processes are tightly controlled. This variability means that collected data needs to be representative of conditions throughout the production process (time, scale, environment, location, etc.) or answer a specific question on a portion of the process (gas emission from small dairies during hot weather conditions when fed corn-silage based diets).

Monitoring may only require that a few of the contaminants listed (next section) be included depending on objectives. Some parameters are relatively simple to inexpensively collect continuously (e.g. air temperature) while others require cumbersome and/or expensive evaluations (e.g. odor), resulting in infrequent collections and few data points that are overly

dependent upon sampling protocols. Location and timing of data/sample collection is often more challenging than the instrumentation choice.

Primary Data:

Reported emission data need to be presented in units that accurately reflect the measurement method, the *primary* units, and typically, in another set of units that are useful for comparisons. Research techniques often dictate how the primary emission units are initially reported. For instance, when quantifying emissions using a wind tunnel or flux chamber the flow rate and source area (footprint of the flux chamber or wind tunnel) provide the primary emission unit as mass/time/area (at a given exchange rate or surface wind speed). Any micro-meteorology method measures ambient contaminant concentrations near a very large source. Using meteorological data and doing some reverse dispersion modeling (e.g. backward Lagrangian) the emission rate is estimated and is in units of mass/area/time. Data collected while monitoring a building source includes the ventilation air exchange rate, pollutant concentration at exhaust, and the size of the building. Size is the most fixed (constant) parameter during the monitoring period versus animal population and average body weight. In all these cases, the primary units of measurement result in mass/time/area. Expressing building emission in terms of area is sometimes problematic since in some barn layouts only a small portion of the surface is the emitting source (dairy freestall or tie-stall barns) and may be confounded by the manure management (hog buildings with deep pit manure storage versus deep-bedded production). Emission, particularly when expressed as a flux, needs to be clear about the measured surface since the total building footprint and the emitting surface area (i.e. manured aisles) may be very different.

The data collection time period may also play an important factor. Typically, the individual measurements are made over a time period of a few seconds (micro meteorology), a few minutes (flux chamber) or a day (for some 24 hour averaging methods). Measurements are reported at standard conditions that must be specified in the data summary documentation; one example is from NIST for pressure (101.325 kPa, 1 atm) and temperature (20°C).

Gas or particulate contaminant concentration obtained outdoors and at facility exhaust:

- Ammonia [NH_3]
- Greenhouse gases [GHG]: methane [CH_4]; nitrous oxide [N_2O]
- Hydrogen sulfide [H_2S]
- Particulate matter less than 10-micron aerodynamic diameter [PM-10]
- Particulate matter less than 2.5-micron aerodynamic diameter [PM-2.5]
- Total suspended particles [TSP]
- Volatile organic compounds [VOCs] or Reactive organic gases (ROG)
- Odor
- Less commonly: Total non-methane hydrocarbons; Ethanol; Methanol; Acetic acid

Air flow containing the gas or particulate matter:

- Mechanical ventilation: fan airflow rates; number and size of fans, timing of fan operation; static pressure difference
- Natural ventilation: airflow rate and direction at openings; opening sizes and timing; wind speed and direction

Flux chamber or wind tunnel: enclosed surface area; tunnel or steady-state chamber needs sweep air flow rate, volume, concentrations of contaminant in entering and exiting air; non-steady-state chamber needs beginning and final contaminant concentrations over a time interval.

Secondary data

Secondary data selection is dependent upon the four types of uses for the emissions inventory, as introduced earlier, and summarized in the following table.

Table 1. Primary and supporting data needs for emission estimates from animal facilities.

Parameter	Regulations Air Pollution	Modeling Process-Based & Dispersion	Life Cycle Analysis & Efficiency	Public Information
PRIMARY				
Gas or particulate	☻	☻	☻	☻
Air flow	☻	☻	☻	☻
Barometric Pressure	☻	☻	☻	☻
Temperature-inside	☻	☻	☻	☻
Temperature-outside	☻	☻	☻	☻
Surface area of emission[1]	☻	☻	☻	☻
SECONDARY				
Environment				
Relative humidity-indoor		☻		
Relative humidity- outside		☻		
Air velocity[2]	☻	☻		
Precipitation		☻		
Sunlight/cloud level		☻		
Weather pattern[3]		☻		
Subsurface temperature[4]		☻		
Operational				
Facility size[5]	☻	☻	☻	☻
Animal population[6]	☻	☻	☻	☻
Animal size[7]	☻	☻	☻	☻
Production of product[8]	☻	☻	☻	☻
Value of product produced			☻	
Feed[9]	☻	☻		
Feed Records[10]	☻	☻	☻	☻
Feed storage description[11]	☻	☻		☻
Manure[12]	☻	☻	☻	☻
Manure management[13]	☻	☻	☻	☻
Manure treatment[14]	☻	☻	☻	☻
Cost of emission reduction[15]	☻		☻	☻
Lighting program with timing		☻		
Animal activity	☻	☻		☻
Equipment (vehicular) and	☻	☻		☻

human activity[16]				
Materials Sampled				
Manure[17], [18]	☻	☻		
Feed[18]	☻	☻		
Bedding[18]		☻		
Product(s)[18]		☻		

[1] surface area such as manure storage or exposed silage face
[2] horizontal air velocity at animal level; wind outside
[3] weather 7-days prior to and during emission measurements
[4] internal pile temperature of compost and feed storage
[5] facility footprint; source surface area; units (i.e. stalls, aisles, pens, etc.)
[6] animal number; species; strain/breed; age
[7] animal mass; growth pattern
[8] food or animal product produced (e.g. kg milk/cow; eggs/hen-house; annual piglets/sow, etc.)
[9] feed ingredients; nutrient composition; chemical composition; method and frequency of feeding; management of residual/spoiled feed; formulated diets
[10] feed volume usage from feed tracking software
[11] feed storage type (bin capacity, bunker, pile or bag surface area and depth); location; protection from precipitation, sun, and wind; equipment traffic; daily area freshly disturbed; daily disturbed feed un-removed
[12] manure solid-liquid designation (moisture content); nutrient composition; pH; mass and volume produced
[13] manure storage location; daily handling routine; removal times; dry matter (bedding) or liquid (cleaning wastes) additions
[14] manure treatment via: pH adjustment; solid-liquid separation; commercial products
[15] costs of treatments or procedures; some examples: sprinkler system, manure additives, application labor, specialized equipment, maintenance labor, manure storage covers, etc.
[16] activity includes: feeding; cleaning; bedding; health checks; mortality collection; etc.
[17] manure for pH, solids, total nitrogen [N], ammoniacal-N, volatile solids, starch, hemicelluloses and cellulose, protein, acid detergent insoluble N; protozoa
[18] often useful for N-balance calculations

Summary

Emissions of aerial contaminants from animal agriculture need to be determined in context with abundant production and management information. Emission in terms of contaminant mass per time per area (e.g. g PM_{10}/day/m^2) is often the primary data collection unit expression from animal housing, manure storage, and feed storage. Additional contextual data will allow the conversion of primary findings into other useful expressions that relate emissions to animal population (g CH_4/day/cow), product production (µg H_2S/day/case eggs), input efficiencies (tons NH_3/year/ton N-fed), and mitigation implementation cost-benefits.

Examples -- Emission Units of Value from Mitigation Perspective

Example of expressing Emissions Factors (EF) from manure in corrals and from silage exposed surface area in units of value from mitigation perspective

Emission factor from manure in corrals

Flux chamber sampling of volatile organic compounds (VOCs) from open lots provided primary data as average flux in $\mu g/m^2/mi$ from a corral of known surface area. Outdoor temperature and atmospheric pressure were used to express emissions in terms of standard NIST conditions (1 atm; 20^oC). Additional data collected included: Number of animals in corral; number of hours/day animals were in the corral; diet and manure samples were collected for nutrient analysis. Seasonally-adjusted turnout average EF was calculated into units of lb/head/year (6.8 with standard deviation of 0.3). Using data in this format leads to the conclusion that the logical mitigation measures to reduce emissions from corral surfaces is to reduce the number of cows on corrals. Utilizing these units (lbs/cow/yr) to express an EF, all cows are assumed to be equal. Based on these EF dairy cows with an average of 50 lbs milk production/day emit the same as dairy cows with an average of 80 lbs milk production/day even though estimates of total manure production estimates for these two populations would be markedly greater for the higher producing cow. The two dairies in the study also differed in offering either 87% or 60% total mixed ration (TMR) diets.

Other than enteric emissions, it is the manure and how it is managed, not the cow, that determines emissions. The control points are with the manure substrates that produce the emissions. Two constituents in manure that serve as substrates for VOC or ammonia emissions will be used as examples to identify the value of identifying and quantifying substrate constituents: starch and urea. Microbes digest starch and yield organic compounds that can be volatilized or are further digested (by different microbes) to yield volatile compounds (including CO_2). Urea is hydrolyzed by urease (enzyme) resulting in formation of ammonium and CO_2. Mitigation measures can be employed to reduce substrate presence (e.g. source reduction through dietary management in the animal) or to modify the environment to either reduce or inhibit formation of the volatiles or volatilization of the formed volatiles.

- Starch Source Reduction. Standard diets fed to lactating cattle in California utilize large volumes of by-product feeds thereby reducing starch excretion. However, estimated starch excretion does vary considerably (between 10 and 50 grams/cow/day) based on dietary ingredients. In locations where more grains and fewer by-products are fed, starch excretion is anticipated to be greater. Managing diets to reduce starch excretion should reduce EF.
- Manure Management. Corral moisture and depth of manure are two key control points to minimize environmental conditions conducive to microbial activity resulting in starch digestion. Reduced emissions typically occur during dry, warm conditions or, the other extreme, wet and cold conditions. Management of solid manure to maximize drying or minimize manure accumulation during conditions where mid-range moisture levels persist may be beneficial to reduce emissions.
- Urea Source Reduction. Urea is a normal metabolic product of nitrogen (N) metabolism in non-avian species. Greater quantities of urea are excreted by animals when dietary inputs

exceed metabolic needs. Dietary modifications to reduce N intake are effective to reduce urea excretion when diets were previously formulated with excess N concentrations.

- Environmental Modifications. Effective management practices may be available to reduce or inhibit the formation of ammonium (e.g. commercial product application to corral surface). Monitoring and modification of manure pH is also a potential tool to manage conversion of ammonium to ammonia and subsequent volatilization.

Some alternative animal housing systems may allow for additional practices whereby contact of urine with feces is minimized (swine manure-belt systems; slotted floor systems in European dairies) thereby reducing formation of ammonia in an environment with large atmospheric contact. In flush systems, more regular collection of manure transfers manure from an area of pH near 8 (concrete floor) to a liquid storage system where pH is 7 thereby reducing emissions of ammonia.

While expression of emissions as an emission factor in this example may favor a lb/cow/year for use in developing a regulatory threshold or establishing an area-wide inventory, such expression were calculated from primary data collected as a mass per surface area over time. For establishing emission mitigation measures and calculating their associated control efficiencies, expression on a per cow basis fails to provide the necessary information. Since it is the manure and not the cow that contains the substrate that yields VOCs would be value in quantifying substrate constituents and reporting EF per unit of total substrate constituents to allow for development and implementation of mitigation measures.

Emission rate from silage exposed surface area

Exposed silage surface area, disturbed during feed preparation, is the substrate from which emissions occur and reducing this area would reduce emissions. Assume a silage face is 1,800 square feet. Emissions are calculated as mass per square foot within four hours of disturbing the face. If silage is managed to remove 6 inches across the entire face twice a day, then the emissions are 2 x 1,800 ft^2 x emission mass/square foot. However, if the face is managed to remove 12 inches from half the pile twice a day then the emissions is 2 x 900 ft^2 x emission mass/square foot. Peak flux is reduced by 50%. Although the same amount of material is removed, disturbing less of the face would theoretically reduce emissions.

Definitions

Concentration – is the mass of a contaminant per unit volume of air (e.g. mg/m^3, ppm or ppb).

Emission rate - the mass of air contaminant released per unit of time (e.g. mg/sec or lb/day) from a source (e.g. g/bird/day). Emission rate is specific to the conditions under which the data were collected and typically represent an instantaneous or short time interval of observation. This is different than Emission Factor (below) but is often used interchangeably, which causes confusion.

Emission flux - the rate at which a contaminant is released per unit source area or length. Flux is expressed as mass per unit of time per unit area or mass per unit of time per unit of length (e.g. $kg/day/m^2$ or lb/hr/ft).

Emission factor –is commonly used to consolidate typical emission rates to represent the long-term quantity of pollutant from an identified source. Emission factors for animal feeding operations have traditionally been expressed on a per-animal basis (e.g. lbs/year/head). Emission factors are usually averages of all available data of acceptable quality and offer representative long-term generalized values useful for estimating a broad impact rather than specific outcomes.

Emissions inventory - the cumulative annual contribution of a category of sources of pollutant generated on a large scale, such as a region or nationally (e.g. tons ammonia from USA poultry per year).

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