AIR QUALITY RESEARCH AND TECHNOLOGY TRANSFER WHITE PAPER AND RECOMMENDATIONS FOR CONCENTRATED ANIMAL FEEDING OPERATIONS

by

Confined Livestock Air Quality Committee of the
USDA Agricultural Air Quality Task Force

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Report Prepared by:
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USDA Agricultural Air Quality Task Force (AAQTF)

EXECUTIVE SUMMARY

U.S. farmers are leaders in producing the safest and most economical food supply in the world. Each year, U.S. consumers spend less than 11% of their income on food. Concentrated animal feeding operations (CAFOs) have largely contributed to the ability of U.S. producers to meet growing demands for the production of meat, milk, poultry and eggs. To maintain a safe and economical food supply, producers must have sufficient lead-time, cost-effective technologies, and resources to adjust to changing public agendas that include air quality protection. To continue this predominance in agricultural production, the USDA Agricultural Air Quality Task Force (AAQTF) established by Congress in the 1996 Farm Bill, recommends an additional $65 million be annually appropriated for agricultural air quality issues. Of this amount, $12.8 million should be specifically targeted for CAFO research needs.

The following information summarizes the findings of the AAQTF in regard to air quality issues associated with CAFOs. A full discussion of the issues can be found in the "Air Quality Research & Technology Transfer White Paper and Recommendations for Concentrated Animal Feeding Operations".

CAFO Air Quality Parameters

- CAFOs can affect air quality through emissions of odor, odorous gases (odorants), particulates (including biological particulate matter), volatile organic compounds and/or some of the so-called greenhouse gases.

- Odor from CAFO sources, as experienced by humans, is the composite of as many as 170 or more specific gases, present in trace concentrations either above or below their olfactory thresholds.

- The primary odorous gases of concern include ammonia and hydrogen sulfide. However, the importance of ammonia and hydrogen sulfide to downwind composite odor as perceived by neighbors is questionable.

- Field and laboratory research has largely focused on measuring concentrations of odor. Data on emission rates, flux rates and emission factors are needed to develop science-based policies for the reduction of CAFO odor and odorants.

- Future research should be directed toward odorous gases that more closely correlate with odor as perceived by humans.

- Carbon dioxide, methane and non-methane reactive organic gases are natural products of manure decomposition. Strategies to reduce emissions of odor and odorants are likely to reduce emissions of these co-product gases.

Emission Factors

- Improved processes for updating emission factors for an array of CAFO-related air contaminants, such as PM_{10}, $PM_{2.5}$, volatile organic compounds and ammonia should be initiated.

Human Response and Health Effects

- Concerns with health effects of odor, odorants, biological and other particulate matter from CAFOs include livestock, employees and neighbors. Recent evidence suggests greater secondary health effects on frequently exposed neighbors than previously documented.

Current Federal and State Policies

- Water quality concerns were first addressed in the Federal Water Pollution Control Act of 1972, which listed CAFOs as point sources. A patchwork of tailored policies and regulations has attempted to address voids of groundwater protection and nutrient management, and only in a few cases have air quality concerns been addressed.

Integrated Programs

- Integrated programs to address air quality from CAFOs have not been funded or developed. A collaboration of agencies is needed to work with issues associated with CAFOs and air quality, just as similar collaborative activities have succeeded in regard to water quality.

Odor Control Technologies

- There are four basic approaches to control odor and odorants: ration/diet manipulation, manure treatment, capture and treatment of emitted gases and enhanced dispersion. Each approach has multiple technologies that need to be tailored on a site-specific basis.

Dust Control Technologies

- Technologies for particulate (dust) control from open-lot feeding systems, where needed, include frequent manure removal, stocking density adjustment to take advantage of excreted manure moisture and water sprinkling.

Research Funding

- A program of accelerated research, education, technical training, technology transfer and financial assistance to address CAFO air quality problems is strongly recommended.

Of the USDA-ARS FY96-99 animal waste research budget of $5.65 million per year and $6.9 million in the CSREES FY97 budget, the amounts devoted to air quality were so small as not to be separately reported.

USDA and EPA funding levels have not been adequate to address or solve air quality problems associated with CAFOs. ***The USDA AAQTF recommends at least $12.8 million per year for coordinated, integrated programs for animal agriculture, as part of the additional $65 million in total funding requested for agricultural air quality.***

RESEARCH AND TECHNOLOGY TRANSFER NEEDS

Numerous research and/or technology transfer needs and opportunities were mentioned in the text of this report. In brief, these include:

- Develop accurate and broadly applicable emission rates, flux rates and emission factors for particulate matter, odor and specific odorants applicable to CAFOs;

- Define emission rates as a function of diurnal, seasonal, and climatic variations, as well as design and management practices;
- Develop effective, practical and economically feasible odor control technologies for confined animals, treatment, and land application systems;
- Determine relationships among odor, odorants, particulates and airborne microbial species;
- Identify kinetic release mechanisms for odorants and odor from principal manure sources and target the development of control technologies accordingly;
- Develop practical ways, capable of widespread adoption, of reducing ammonia from CAFOs;
- Transfer economically viable technologies for odor control to ALL producers regardless if they are a CAFO or animal feeding operation (AFO);
- Develop innovative air treatment processes for confinement building exhausts or covered lagoon surfaces;
- Develop odor reduction treatments for use prior to land application;
- Develop accurate standardized measurement technologies for odor, odorants of principal concern, and fine particulate, and ensure these systems become widely available for research and demonstration; this should include electronic measurement devices that are well-correlated with the human odor experience;
- Develop accurate dispersion models for odor, odorants, and PM appropriate to specific types of CAFOs, addressing the inherent problems of Gaussian models;
- Characterize air quality as a function of distance from CAFOs;
- Implement cooperative industry/agency/university programs for scientific evaluation of new products for producers' consideration and adoption;
- Assess the importance of indoor air quality at CAFOs and devise ways to reduce exposure levels;
- Devise suitable acceptability criteria for community-level exposure to odor and specific associated gases;
- Assess potential relationships between emission constituents, concentrations, and potential health indicators, and devise appropriate mitigation strategies accordingly;
- Establish partnerships with health research organizations to identify potential health concerns associated with CAFOs.

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INTRODUCTION

Animal agriculture in the U.S. is important to the nation's economic well being, producing almost $100 billion per year in farm revenue contributing to the vitality of rural communities and insuring the sustainability of America's food supply (GAO, 1999). The U.S. has developed a very efficient, sophisticated system for production of meat, milk, poultry, and egg products involving concentrated animal feeding operations (CAFOs). For instance, the United States has 99.0 ± 0.9 million cattle and calves (average ± standard deviation for 1998-2000), and in 1999, a monthly average of 10.32 ± 0.75 million head were in beef cattle feedlots being finished for slaughter (TCFA, 2000). These finishing cattle generally range in liveweight from 272 kg (600 lbs) to 544 kg (1,200 lbs) per head, with an average liveweight of approximately 408 kg/hd (900 lbs/hd). During a normal 150 day finishing period, each animal excretes about 900 kg (2,000 lbs) of collectible manure, or about 1,800 kg/hd (4,000 lbs/hd) of manure per head of feedlot capacity per year. Cattle feedlots in the U.S. produce an estimated 18 million metric tons/yr (20 million tons/yr) of collectable manure containing at least 360,000 metric tons/yr (400,000 tons/yr) of total nitrogen and 135,000 metric tons/yr (150,000 tons/yr) of total phosphorus (P).

State and federal regulations have directly addressed water quality protection from CAFOs since the early 1970s. Accordingly, in the last 30 years systems designed for manure and wastewater management have historically been optimized for water quality protection to comply with EPA effluent limitations guidelines (ELGs) adopted in 1974 and 1976, and currently being updated. Most states have surpassed USEPA in requiring groundwater protection measures, nutrient balances for land application of manure and wastewater. Air quality protection has received secondary consideration. Changing regulatory priorities now have begun to include phosphorus and pathogens in water quality goals and particulate matter, odor, and/or specific odorants in air quality as goals. For example, ammonia volatilization was considered a desirable means to balance N for land application, and only recently has ammonia loss been viewed as a potential problem in terms of air quality considerations.

Water and air quality issues are interrelated. There has been a major lack of adequate research to deal with both water and air quality issues in a holistic systems approach while maintaining high standards of confined livestock productivity, animal health, and production cost efficiency. For example, EPA's anticipated update of Effluent Limitation Guidelines will likely embrace phosphorus (P) limits in land application criteria, and lead toward reduced manure and wastewater application rates in some watersheds. In turn, this may increase producers' incentives to reduce N loss and retain N to more nearly balance nitrogen application rates. Increased funding is needed for research and development that will properly quantify particulate matter (PM) and gaseous emission rates as a function of system design and operational parameters. Public interest in these issues will need to be tempered by realizations of needed lead time, resources, and appropriate technologies for producers to meet a changing public agenda and avoid major dislocations in animal agriculture, which is an area of very significant U.S. leadership in the world.

AIR QUALITY PARAMETERS AND CONCERNS

Concentrated animal feeding operations (CAFOs), including swine and poultry operations, dairies and cattle feedlots and the associated animal waste management systems may produce emissions of odor, odorants, odorous gases, such as ammonia, H_2S, VOCs, "greenhouse" gases

(CO_2 and CH_4), and PM. Regardless of type of contaminant, the emissions load on the atmosphere in terms of mass per unit time is the product of contaminant concentration and the air flow rate (e.g., load = concentration x ventilation rate).

1. Odor and Odorants

Principal sources of odor emissions may include:

- Production Facilities -- open lot and confinement buildings;
- Manure/wastewater storage and/or treatment systems-- ponds, pits, lagoons, stockpiles, composting operations;
- Land application systems for solid or liquid manure, treated effluent, or open lot runoff; and
- Animal mortalities/carcasses.

Odor may become an annoyance to, and affect the well being of, nearby residents. Odorous gases (odorants) arise from feed materials, fresh manure, and stored, decomposing or treated manure, and wastewater. Eaton (1996) listed 170 different compounds present in swine manure odor. Odorous gases emitted from animal waste include ammonia and amines (Hutchinson et al., 1982; Peters and Blackwood, 1977), sulfides, volatile fatty acids, alcohols, aldehydes, mercaptans, esters, and carbonyls (National Research Council, 1979; Miner, 1975b; Barth et al., 1984; ASAE, 1999a). Peters and Blackwood (1977) listed 31 odorants identified at cattle feedlots, together with their threshold limit value (TLV) in ppm and odor threshold (ppm), where known. An olfactory threshold value detected by human panelists is the concentration where half the panelists detect and half do not detect an odor. Consequently, the threshold value may span a range as great as 5 or 6 orders of magnitude for a single compound and range from as low as 7.5×10^{-8} ppm for skatole to as high as 12,000 ppm for formaldehyde (Eaton, 1996). For instance, ammonia has reported odor threshold values spanning three orders of magnitudes ranging from 0.0317 ppm to 37.8 ppm (Eaton, 1996). Concentrations of odorants at downwind locations are very low; however, some may exceed olfactory threshold values and create nuisance conditions (Sweeten, 2000b). Odorous compounds generally have not been considered toxic at concentrations found downwind of livestock feeding facilities. Mackie et al. (1998) and Tamminga (1992) cited lowest toxic values (LTV) of frequently cited odorous gases from confinement buildings. These LTV values were from 5 to 20,000 times higher than cited odor threshold values for these compounds. However, recent evidence suggests potential for adverse health effect in some instances (Wing and Wolf, 1999).

Odor characteristics that contribute to nuisance conditions are as follows: (a) the intensity, concentration or strength of the odor; (b) the odor frequency or number of times detected during a time period; (c) the duration of the period in which the odor remains detectable; (d) the perceived offensiveness and character or quality of the odor (Jones, 1992). These factors interrelate in causing nuisance conditions. Odor frequency and duration are partly dictated by climatic conditions, including wind-direction frequency, atmospheric stability, and moisture conditions.

A weak link in developing odor abatement technologies has been an inability to precisely quantify odor strength with sufficient reproducibility and accuracy (Clanton et al., 1999b). Odor measurement methods have been applied to animal waste management systems (Bulley and

Phillips, 1980; Barth, et al., 1984; Watts, 1991; Sweeten, 1995; McFarland and Sweeten, 1995). General approaches to estimate the strength or intensity of livestock manure odors include:

a. Sensory methods that involve collecting and presenting odor samples to human panelists (diluted or undiluted) under controlled conditions, e.g., Scentometer, dynamic olfactometers, suprathreshold referencing methods, absorption media, etc.
b. Measurement of concentrations of specific odorous gases (directly or indirectly).
c. Electronic "nose" devices that register presence, concentration or activity of selected odorous gases.

Olfactometry is the most widely used method to evaluate odor concentration. Perhaps the simplest method of field sensory odor concentration measurement is the Barnebey-Sutcliffe Scentometer (Barnebey-Cheney, 1987). This simple, portable field instrument involves direct sampling of the ambient air, and it has been used as the basis for setting property line odor concentration standards by several states (e.g., Colorado, Montana, North Dakota) and cities. The Scentometer has also been used for field odor measurement at numerous livestock and poultry operations in the U.S. (Sweeten et al., 1977; Sweeten et al., 1983; Miner and Stroh, 1976; Sweeten et al., 1991) and in data collection contributing to nuisance litigation (Sweeten and Miner, 1993). The use of suprathreshold referencing (ASTM, 1975) for measuring intensity of livestock waste odor was described by Sweeten et al. (1983 and 1991). The deployment and improvement of dynamic triangle forced-choice olfactometers (DTFCO) (ASTM 1991; Dravnieks and Prokop, 1975) for livestock odor research is occurring rapidly (Watts, 1991; Jones, 1992; Nicolai et al., 1997; Li et al., 1997) and appears to be the instrumentation of choice for sensory odor measurement for current research. For instance, Lim et al. (1999) reported odor concentrations, measured by 8 panelists with a dynamic triangle forced-choice olfactometer, for swine nursery buildings with underfloor liquid manure storage pits, as 190 odor units (OU)/m^3 in the exhaust air and 18 OU/m^3 outside the building. The data were used to calculate an odor emission rate per head (51 OU/hd/sec) or per unit area (2.1 OU/m^2/sec) using airflow rate data. Regression relationships were found between odor concentration, odor intensity, and odor offensiveness. Similar data using a DTFCO system was reported by Heber et al. (1998) for four 1,000 head finishing buildings, which produced an average odor concentration of 294 ± 65 OU (range of 12-1,586 OU), and an emission rate of 96 ± 30 OU/hd/sec, or 5.0 OU/m^2/sec.

Pain et al. (1988) used a small wind tunnel (2 m x 0.5 m x 0.45 m) to collect samples of odorous air and to measure ammonia emissions following the surface spreading of liquid dairy cattle manure (1 to 2 day storage time), before and after mechanical separation with a roller press, onto grassland in the United Kingdom. Odor samples were collected beneath the flexible plastic sheet canopy into 50 L Tedlar bags inflated within 4 to 5 minutes time. Odor concentration was measured by 4 to 8 panelists using dynamic olfactometry with 4 to 6 dilutions of each sample presented for determination of the odor threshold (ED_{50}) value. The odor emission rate was calculated as the product of odor units (OU) and the volumetric airflow rate (odor units/m^2/hr). The odor emission rates measured by Pain et al. (1988) for liquid dairy manure spread on pastures were reported by Smith and Watts (1994) at 22 OUm/s and 11 OUm/s at time intervals of 3 and 48 hours, respectively, after spreading. In essence, the odor emission rate was reduced by 50% two days after spreading liquid manure. Similar values were obtained for swine manure slurry. Total odor emissions were similar for whole dairy cattle manure slurry and separated slurry (Pain et al., 1988).

Despite standardization and control procedures to reduce bias, elements of subjectivity and sources of imprecision remain in odor measurement with sensory panels. Combined with the high cost per sample of large odor panels, this creates the need for reproducible, inexpensive instruments that mimic the human olfactory response (Lacey, 1998).

Clanton et al. (1999b) evaluated several possible sources of variation in determining dilution to threshold odor units using a dynamic triangle forced choice olfactometer. For the same samples, two different 8-person odor panels consistently produced 22 to 50% differences odor concentration (measured in odor units), depending on odor strength. Two different olfactometer airflow rates resulted in 9 to 28% differences in odor units. There were large differences in individual panelist sensitivity to odor detection and likewise variations by individual panelists across different testing days and within a testing session. A learning curve for individual odor panelists was demonstrated. To improve the probability of detecting significant reductions in odor resulting from a particular treatment, Clanton et al. (1999b) recommended that several identical pairs of air samples will be needed, together with a sufficient number of panelists to achieve statistically significant differences with current olfactometry technologies.

Considerable effort has been devoted to identification and measurement of specific gases within the atmosphere of livestock and poultry confinement buildings (Burnett, 1969; Elliot et al., 1978; Hammond and Smith, 1981). A large number of odorous compounds are present in very low concentrations. Miner (1974) reported that the measured concentration of each gaseous compound identified in animal waste odor was below the reported minimum olfactory threshold. Zahn et al. (1997) reported that volatile organic acids with carbon numbers from 2 to 9 demonstrated the greatest potential for accounting for manure odor.

Instruments available to identify and measure the concentrations of specific odorous gases (odorants) emitted from animal manures include gas chromatography and mass spectrometry (GC/MS) (White et al., 1971; Hammond et al., 1974). These methods are very sensitive in detecting compounds in very low concentrations. Peters and Blackwood (1977) reported difficulty in positively identifying compounds present in feedlot air samples using GC-FID (gas chromatography-flame ionization detector) technology. Low peak values precluded the use of GC/MS for amines. As a result of the low concentrations of many odorants in and around CAFOs, the compounds may need to be concentrated further prior to analysis by use of methods such as solvent desorption, thermal adsorption (Wright, 1994: Zahn et al., 1997) or solid-phase microextraction (SPME) (Zhang et al., 1994).

An electronic nose is an array of gas sensors that are combined with pattern recognition software to mimic human olfactory response (Lacey, 1998). Current commercial applications are focused on high-valued food products. Lacey (1998) and Mackay-Sim (1992) listed electronic approaches to volatile gas (odor) detection: metal-oxide semi-conductors; field-effect transistors; optical fibers; semi-conducting polymers; and piezo-electronic quartz crystal devices. These approaches raise the possibility of remote odor monitoring/surveillance networks for individual compounds or odorant mixtures. The piezo-electric crystals are sensitive to changes in surface mass caused by interaction with gaseous molecules. As mass is added to the surface, the resonant frequency decreases. The sensor surface can be designed to respond to single chemicals or groups of chemicals. Berckmans et al. (1992) in Belgium developed a thick film semiconducting metal oxide sensor for monitoring ammonia concentrations within, and emissions from, livestock confinement buildings. Some sensors may be affected by water vapor, methane, and temperature (Lacey, 1998).

Collection and storage of odorous air samples for presentation to panelists or instrumental analysis is an important consideration (Sweeten, 1995). Tedlar bags (10-50 L) that are inflated in the field using portable wind tunnel or negatively-pressurized canisters have become the most commonly used method.

Schmidt et al. (1999) described wind tunnel design parameters for odor sampling and concluded that odor and hydrogen sulfide concentrations and corresponding emission rate increase with bulk wind speed of the tunnel according to a power function relationship. Results of Schmidt et al. (1999) corroborated earlier work by Smith and Watts (1994b) on open unsurfaced cattle feedlots.

2. Major Gases of Concern – Ammonia and Hydrogen Sulfide

Ammonia is one of the fixed gases of both aerobic and anaerobic decomposition of organic wastes. Much of the nitrogen excreted by cattle is in the form of urea, which rapidly hydrolyzes to NH_3. Additional NH_3 as well as amine are produced during microbial breakdown of fecal material in confinement buildings, on feedlot surfaces, in stockpiles, and in lagoons or runoff retention ponds. Ammonia evolution rates are a function of time, temperature, pH of the manure surface, and level of biological activity. Ammonia (NH_3) volatilization is probably the most important pathway for on-site loss of nitrogen in animal manure to air and water resources. There are four main sources of ammonia emissions on a commercial swine facility: confinement buildings, manure and storage treatment lagoons, land application of lagoon effluent to cropland, and potential NH_3 re-emission from the soil (Aneja et al., 2000a). In the atmosphere, ammonia can react with acidic species to form ammonium sulfate, ammonium nitrate, ammonium chloride, or particulate (Aneja et al., 2000a). Battye et al. (1994) reported that ammonia in the atmosphere can have a significant effect on oxidation and deposition rates of acidic compounds.

Ammonia concentrations can be measured by packed bed chemical-specific syringe tubes that are primarily used in occupational safety and health applications (Sweeten et al., 1991). A second approach is GC/MS as mentioned previously in which odorant samples are presented to the GC/MS either by vapor syringe or by solid-phase microextraction. The third approach is an ammonia (and amine) absorption trap in which a known volume of air is passed through a weak acid media: sulfuric acid solution (Luebs et al., 1974; Hutchinson et al., 1982; Cole and Parker, 1999); boric acid solution (Moore et al., 1995; O'Halloran, 1993); sulfuric acid-impregnated fiberglass (Peters and Blackwood, 1977). The ammonia-absorption technique allows for comparisons of ammonia concentrations and emission rates between various times and locations (White et al., 1974). A fourth approach (Oosthoek and Kroodsma 1990; and Phillips et al., 1995), involves chemoluminescence, in which ammonia and NO_2 are converted to NO at 750°C. In a split airstream at 350°C, the NO_2 is converted to NO. Ammonia concentration is calculated as the difference in NO concentration between the 350° and 750°C airstream. Prior U.S. research has indicated that ammonia is emitted from surfaces of open, unpaved cattle feedlots and dairy corrals at concentrations of 360-980 $\mu g/m^3$ as compared to background levels of 1-4 $\mu g/m^3$

(Sweeten et al., 1999). Ammonia volatilization losses are reportedly 50% or more of total N excreted from open lot surfaces and 23-70% following field spreading of manure.

Luebs et al. (1974) measured ammonia concentrations at 1.2 m height upwind and downwind of open-lot dairy operations near Chino, California, in which 145,000 dairy cows were concentrated in several farms within a 60 square mile area near Los Angeles. Concentrations of ammonia (distillable nitrogen) were below the odor threshold concentrations reported for ammonia. An ammonia concentration of 540 Φg/m^3 was measured at the downwind corral fence of a 600-cow dairy. This concentration was reduced to 18 Φg/m^3 at a downwind distance of 0.5 miles (0.8 km). By comparison, ammonia concentrations were 92 ± 89 Φg/m^3 at Chino airport near the center of the dairy area and 4 ± 2 Φg/m^3 at a non-agricultural reference site. Diurnal fluctuations were observed in ammonia concentration at the Chino airport with highest concentrations between 1800 and 2200 hours (184 Φg/m^3) and 0600 to 1000 hours (128 Φg/m^3). Much lower ammonia concentrations occurred in afternoons 1400 to 1800 hours (6 Φg/m^3). Fenceline observations at an individual dairy did not coincide with the diurnal pattern at the center of the dairy area.

Ammonia volatilized from liquid dairy manure slurry spread on pastures was measured (Pain et al., 1988) by drawing air samples from the tunnel inflow and outflow sections through absorption flasks containing orthophosphoric acid (0.005 M). Ammonia losses following application were 23 to 70 percent within 10 to 14 days after application, although 80 percent of these losses occurred within 2 days of application. There was a strong correlation ($r^2 = 0.94$) between odor emissions and ammonia emissions following application of dairy cattle slurry to the grassland pasture. A similar relationship was obtained for swine manure slurry. A greater proportion of ammonia was lost from dairy cattle slurry than from swine slurry.

Montes and Chastain (2000) evaluated ammonia losses from sprinkler irrigation of swine lagoon effluent at two tree plantations (2 and 8 years old) in South Carolina. As compared to prior research of others (1980-1997) which reported 10-60% ammonia-nitrogen loss through sprinkler irrigation, they observed erratic losses ranging from (-) 40% to (+) 38%, with a mean value of 2% ± 16%.

Keck (1997) determined the influences of manure removal frequency, climatic conditions, and exposed surface area on ammonia emissions from cattle exercise yards and from wind tunnel simulations of 7 m^2 manured surfaces where airflow volume could be determined. Ammonia concentration was determined using HCl absorption. Urine caused more than 8 times greater ammonia emission per unit area than feces (205 mg/m^{2}h vs. 25 mg/m^2/h). Daily removal of manure (feces and urine) produced a small decrease in ammonia emission compared to removal at three-day intervals. Ammonia emissions were greater in warm season than in cold weather. Reducing the surface area of manure decreased the ammonia emission.

Schmidt et al. (1997) conducted field measurements at 5 dairies in Southern California during winter and summer seasons to determine surface emission rates of ammonia and other compounds implicated in contributing to PM 10 emissions. Sampling was conducted using a surface isolation flux chamber (EPA, 1986). Of the compounds studied, ammonia had the highest flux rate. Manure stockpiles that were disturbed produced the highest ammonia flux rate. Amine compounds were not detected above the detection threshold. The average ammonia emissions for 4 dairies was 11.2 ± 4.3 kg/cow/year projected from the late summer/early fall testing period, and was 4.8 ± 1.1 kg/cow/yr projected from the winter testing period.

Oosthoek and Kroodsma (1990) reported monthly ammonia concentrations of 3.0-4.8 mg/m^3 from a 40-cow dairy free-stall housing unit. Monthly ammonia emission rates ranged from 39 to 60 kg/month, or 1 to 1.5 kg/head/month, where cattle were housed at night. A scraped concrete floor had three times the ammonia emission rate of a flushed concrete floor (600 mg/m^2/hr vs. 200 mg/m^2/hr).

Peters and Blackwood (1977) measured both ammonia and hydrogen sulfide concentrations at two cattle feedyards on the Texas High Plains. These one-time measurements were:

a. Ammonia -- 104-120 μg/m^3
b. Total Sulfide -- 5-27.5 μg/m^3

There was no correlation between the NH_3 and H_2S concentrations.

Battye et al. (1994) examined the European literature to arrive at what they termed "rough estimates" of ammonia emission factors for agricultural and nonagricultural sources in the U.S. The NH_3 emission factors recommended for use in future U.S. emissions inventories were based primarily on European factors for animal agriculture and fertilizer application. The relative contribution of animal agriculture to the total U.S. ammonia emission inventory was extrapolated to be as follows: all cattle and calves (43.4%); swine (10.7%); poultry (26.72%); sheep and lambs (0.7%). All other sources constituted only 18.5% of total estimated ammonia emissions but several sources including undisturbed soils were not evaluated. The "all cattle and calves" inventory included both unconfined (range and pasture) beef and dairy cattle as well as beef feedlots and dairies, and similarly for the sheep and lambs category. The primary source of data for the Battye et al. (1994) assessment was Asman (1992), who summarized literature in the Netherlands through 1990. Battye et al. (1994) recommended several research areas, including U.S. animal agriculture, to enhance the quality of ammonia emission factors available.

Factors influencing ammonia emissions from livestock operations include (Battye et al., 1994): type and size of animal; ration N and amino acids content; N digestibility and conversion; confinement housing system; and manure handling system. Following spreading, ammonia emissions are influenced by: climatic conditions, soil properties, manure properties, application rate, application method, and timing of soil incorporation.

Buijsman et al. (1987) likewise produced ammonia emission factors from data in the United Kingdom. The ammonia emission estimates of Asman (1992), Buijsman (1987), and NAPAP represented both confined and unconfined cattle and sheep, with values for the pastured animals reportedly higher than confined animal. Likewise, larger animals within species reportedly produced higher ammonia emission factors, and vice versa. However, the data sets failed to distinguish in similar terms among types of production systems, housing, or sizes of animals used for the data series, nor between monitoring methods. Table 1 shows a comparison of NH_3 emission factors for the three European studies and a derived composite value of Battye et al. (1994) for use by EPA, in which they took into account types, size, ranges and numbers of farm animals in the U.S. The National Acid Precipitation Assessment Program (NAPAP) for the U.S.

(Warn et al., 1990) reported NH_3 emission factors that Battye et al. (1994) described as "quality rating E (lowest possible)."

Preliminary estimates of ammonia emissions from typical open-lot dairies and beef cattle feedlots in California were developed by the California Air Resources Board (CARB, 1999), which commented that because of "uncertainties in the number of animals and the ammonia emissions per animal, it is not possible to produce precise measurements of regional livestock emissions as can be done for factories or cars". Their estimates for livestock are based on averages in developing an ammonia emissions summary for 15 air quality basins. Difficulties in arriving at these estimates included partitioning cattle numbers, liveweights, and time segments into different phases of each type of operation using standard livestock statistics developed for other purposes. Moreover, CARB (1999) stated that researchers' attempts to quantify ammonia emissions from cattle are "an extremely difficult process; in that emissions vary by type of ration, climate conditions (temperature, humidity, etc.), type of animal housing or stabling, where and how measurements were taken, and diverse activities that may contribute ammonia (e.g., grazing, confinement, manure handling/storage/spreading, etc.)."

Because of these difficulties, CARB (1999) estimated emission factors for cattle feedlots based on the Battye et al. (1994) report, which itself was based on European data (Asman, 1992) as noted previously. Accordingly, the weighted-average composite beef cattle emission factor for all beef cattle and calves in California was taken as 18 lbs NH_3/hd/year. Similarly, the derived composite estimate for dairy cattle was 30 lbs NH_3/hd/year, as compared to cited emission factors of 17-87 lbs/hd/yr for dairy cattle.

Data on ammonia concentrations in cattle feedyards and emission flux rates (mass per unit area) are sparse, and area from feedlot and holding pond surfaces is sparse. Ammonia-nitrogen (NH_3-N) concentrations measured on 13 days from a 120,000-head feedlot near Greeley, Colorado, Hutchinson et al. (1982), were compared with measured background concentrations of 1-4 Φg NH_3-N/m^3. Average concentrations above the feedlot surface were 520 ± 309 Φg/m^3. Concentrations on the 10 "dry days" averaged 361 ± 46 Φg/m^3, and peak concentrations occurred either when the feedlot was drying out (2 days) after rainfall (1,090 μg/m^3) or during an inversion (1 day), when the concentration was 970 Φg/m^3. Conversion of concentration data to flux densities requires site specific concurrent data on wind speed, temperature, solar radiation, and boundary layer thickness. Hutchinson et al. (1982) estimated vertical flux densities of 0.64-2.37 kg N/ha/hr, with an average value of 1.4 kg N/ha/hr. The highest ammonia concentrations and flux densities were measured when the feedyard surface was drying out after rainfall.

Ashbaugh et al. (1998) conducted several field studies in the San Joaquin Valley, California, to determine upwind and downwind ammonia concentrations. Ammonia concentrations were highly variable from different parts of the dairy. Secondary ammonium nitrate particles form in the atmosphere from ammonia gas and nitric acid. Dairy facilities used were a 2,050 cow free stall (milking herd size) with 2,350 non-producing heifers on property in open corrals. The flushed manure from the free stall barn and milking parlor entered a two-stage solids separation system (gravity settling basin and mechanical separator) followed by a primary (single-stage) anaerobic lagoon. Solid manure was collected from drylots by conventional scraping. Ammonia was sampled using two approaches:

- Active samplers -- two-stage boric acid traps;
- Passive samplers -- citric acid coated filter Teflon protective filter inside a standard Millipore filter cartridge, further described in Freitas et al. (1997).

Meteorological conditions were monitored to a 12-meter height to allow calculation of ammonia flux and to determine data quality. The vertical flux (mass/unit area/unit time) was used to calculate an emission rate in mass/unit time. The emission factor was calculated from the emission rate divided by the number of animals at the dairy. Diurnal effects were noted as emission factors ranged from 24 lbs/hd/year at night to 227 lbs/hd/year in the late morning. These results (Ashbaugh et al., 1998) appeared to bracket the following prior estimates/ measurements of emissions factors for dairy cattle:

Prior Source	lbs/hd/year	Data Source
• Battye et al, 1994	87.6	Europe
• Gharib & Cass, 1984	48.9	S. California
• James et al., 1997	74 ± 130	San Joaquin Valley
• Schmidt et al., 1997	11-25	S. California
Atwood and Kelley, 1996		

Ni et al. (1998) observed ammonia emissions from a 1,000 head swine finishing building with underfloor liquid manure storage pit of 11.2 ± 4.6 kg/day, or about 13 g/day/head on feed. These in-building concentrations were generally lower than reported in the European literature. The emission rate varied with pig weight, ventilator rate, and indoor air temperature.

Stowell et al. (2000) obtained average ammonia concentrations of 16.1 ± 11.6 ppm in fan exhaust air from a finishing building for 960 hogs with a solid manure handling system, although concentrations varied among fans and between sampling events. The average ammonia emission rate for this unconventional type of swine housing was 27.6 g/min (4.1-59.0 g/min), or 41 g/day/head, which is about three times the value of Ni et al. (1998) (above). The ammonia concentration diminished rapidly with downwind distance from exhaust fans, to only 1.8 ppm at 3 m, 0.3 at 15.2 m and 0.1 ppm at 30.5 m (100 ft).

Tanaka (2000) determined that 80% of the ammonia emissions from a forced-aeration dairy manure/sawdust composting system occurred within the first 3 days, and 90% of ammonia losses occurred within the first 2 weeks. Ammonia loss was accelerated by low C/N ratio, with finished compost substituting for sawdust. These results are consistent with Sweeten et al. (1991) who used a negative-pressure collection system to capture and treat (via biofilter) gases from the first week of a 4-week composting cycle for fresh caged layer manure plus peanut hulls.

Aneja et al. (2000a) measured seasonal fluxes of ammonia nitrogen (NH_3-N) from a 6.1 acre (2.5 ha) x 13 ft (4 m) swine manure treatment lagoon at a 10,000 head (~ 1,000 sow farrow to finish) operation in North Carolina for nearly a year (1997-98). A floating dynamic-flow flux chamber was used to capture and sample gaseous emissions. Ammonia fluxes varied seasonally ranging from an average of 305 (February) to 4,017 (August) $\Phi gN/m^2/minute$ (Table 2).

The ammonia flux increased exponentially as the lagoon surface water temperature increased from 8°C to 38°C (Aneja et al., 2000a and b). This is related to diffusion and mass-transfer principles. There was no correlation between ammonia fluxes and total Kjeldahl nitrogen concentrations in the lagoon supernatant. They used GIS satellite images of North Carolina swine lagoons surface areas, along with the above season average flux rates to compute an estimated total ammonia emissions from swine lagoons. The total for the lagoons was estimated to be 33% of the state's total swine ammonia emissions of ~68,450 tons NH_3-N per year, with the total developed independently from other published sources, including Battye et al., 1994.

Brewer and Costello (1999) reported that ammonia fluxes from broiler litter (initial equal mixture of rice hulls and pine shavings) increased with number of grow-out cycles in which the litter was reused. Ammonia fluxes averaged 149 mg NH_3-N/m^2/hour (range of 0 - 314) during the first grow-out cycle and 208 mg NH_3-N/m^2/hour (range of 40-271) on reused litter. Flux values varied by location within the broiler houses, and were greatest adjacent to watering locations due to greater manure deposition and water spillage. Variations also occurred with respect to bird age, being least during the first week and highest after 15 days through the end of the grow-out period. Ammonia flux from new litter was less than from old (reused) litter only during the first 3 weeks of the initial grow-out period.

Ammonia from swine facilities in a six-county region with an average hog population of 1,350 hogs/sq mile (528 hogs/km^2) in North Carolina are believed to be impacting precipitation caught in National Atmospheric Deposition Program/National Trend Network (NADP/NTN) monitoring sites up to 50 miles (80 km) away (Walker et al., 2000).

Hydrogen sulfide is one of the main gases produced from anaerobic decomposition of swine manure, and can cause serious indoor air quality problems in confinement swine buildings with underfloor manure storage pits (Arogo et al., 1999). H_2S can cause adverse health effects to animals and humans (dizziness, headache, irritation, etc.) at concentrations as low as 10 ppm, and at high concentrations can cause death. Hydrogen sulfide is formed and released at low pH conditions (below 7), and is nonexistent at pH above 9 or 10. Arogo et al. (1999) found that the mass transfer coefficient of H_2S increases with liquid manure temperature, and that higher emission rates of H_2S are likely to occur when liquid temperature is higher than air temperature.

The Minnesota Pollution Control Agency (MPCA) recommended three methods of H_2S monitoring (Sullivan et al., 1999):

a. Total Reduced Sulfur (TRS) -- continuous method that uses a thermal oxidizer to convert reduced sulfur compounds including H_2S to a measurable form with an EPA approved sulfur dioxide analyzer;
b. Sensitized paper tape monitor -- continuous monitor that detects and quantifies dark stain produced by H_2S;
c. Gold film H_2S monitor -- portable, handheld H_2S gas analyzer; suitable for grab samples.

MPCA monitored 137 animal feeding facilities for hydrogen sulfide emissions in 1998, and found that 24 operations demonstrated a "potential to exceed" the state's ambient air quality standard of 30 ppb for a one-half hour averaging period.

The MPCA team's observations were not uniformly distributed based on animal species, size or type of operation, and half were selected based on prior complaints. Highest concentrations came from swine and poultry facilities total confinement systems, and from earthen storage basins for liquid manure (not treatment lagoons). There was essentially no correlation between size of operation (based on number of head) and H_2S concentrations at or near the property line (Sullivan et al., 1999).

Bicudo et al. (2000) continuously monitored H_2S at and around three swine farms (1,800-3,000 hd) and one dairy farm (667 hd) in Minnesota for 30 days. The continuous air monitors were located at varying distances and directions from the confinement buildings or earthen basins. Agitation and pumping of the manure storage units occurred for 1 to 10 days in August or September. Air samples collected in 10 L Tedlar bags for analysis by odor panels or H_2S instrumentation. Peak concentrations of H_2S during agitation and pumping of earthen basins for manure storage were significantly higher than from the basins with deep pits, and frequently exceeded the 92 ppb recording range of the continuous air monitors for about 4 hours, then decreased rapidly to levels below 30 ppb. Even during agitation and pumping, odor concentration (OU) and H_2S diminished rather rapidly with distance downwind, to levels of below 20-50 OU and 0-30 ppb, respectively, at distances of 200-250 m.

Ni et al. (1999a) reported H_2S emission rates from two 1,000 head grow/finishing swine buildings with underfloor liquid manure storage pits. H_2S emission rates averaged 0.591 kg/day per building (range of 0.32-1.867 kg/day), which equated to 740 mg H_2S/day/m^2 building floor area. Average H_2S emission per head of building capacity was 6.3 mg/hd/day. Emission rates for H_2S were directly proportional to room temperatures and airflow rates but pig size was not a significant parameter. According to Ni et al. (2000), prior work has reported 5 to 95 mg H_2S/m^2/hour from swine finishing buildings in the Upper Midwest. There is a need to identify other important odorous compounds and determine how they are generated and how to control them. Ni et al. (2000) found that SO_2 was produced in simulated liquid manure storage pits along with H_2S, but at about one-tenth the concentration (e.g., 20-25 ppb SO_2). Releases of H_2S fluctuated more drastically than for SO_2.

3. Particulate Matter – PM_{10} & $PM_{2.5}$

The cattle feedlot industry is under increased scrutiny and regulatory involvement at state and national levels with regard to particulate matter (PM) emissions from fugitive sources. USEPA (1987) replaced the total suspended particulate (TSP) standards for all sources in the U.S. with a PM_{10} standard based on particulate matter (PM) having mass median diameter of 10 microns (Φm) (AED). In essence, the revision was based on the premise that relatively fine, rather than coarse dust, needs to receive greater focus in protecting human health. The PM_{10} primary and secondary 24-hour standards were changed to 150 Φg/m^3 for a 24-hour average with no more than one exceedance per year (USEPA, 1987). Two instruments (manufactured by Wedding and Associates and by Sierra Andersen) were accepted for PM_{10} measurement by the USEPA, and other instruments or methods have been developed as well (Herber and Parnell, 1988).

A procedure developed by Raina and Parnell (1994) involved use of a Coulter Counter to determine particle size distribution of particulate collected with a high volume sampler and, based on these measurements, mathematically deriving the PM_{10} concentration. Their data with agricultural processing dusts suggested that the Coulter Counter method may give a more accurate indication of (a) median aerodynamic particle diameter, and (b) cumulative PM_{10} concentration.

With increasing concerns for human health effects believed caused by fine particulate matter (respirable dust), the USEPA proposed new National Ambient Air Quality Standards (NAAQS) in July 1997. The proposal would provide new primary and secondary standards for PM$_{2.5}$ (AED). The proposed 24-hour primary and secondary PM$_{2.5}$ standard was 65 **Φ**g/m^3 calculated as the 3 year average of the 98th percentile reading at each monitor. The proposed annual standard was 15 Φg/m^3 as the 3-year average of annual arithmetic means. In addition to the new PM$_{2.5}$ standard, the 1987 NAAQS for PM$_{10}$ would be left in place, except that the PM$_{10}$ exceedance criterion for 24 hour samples would be changed to 99th percentile (i.e., 4th highest concentration) rather than one exceedance per year. It is important to note that the proposed new NAAQS has not been adopted by USEPA due to a 1999 court decision. The current NAAQS for PM$_{10}$, as well as the other criteria pollutants are provided in Table 3. The PM$_{10}$ primary standards are 50 Φg/m^3 for the annual arithmetic mean, and 150 μg/m^3 as the 24-hour maximum concentration (Woodford, 2000).

Measurements of total suspended particulate (TSP) with standard high volume samplers both upwind and downwind of 25 California feedlots during the summer resulted in an average net TSP concentration of 654 Φg/m^3 with a range of 54 to 1,268 Φg/m^3 (Algeo et al., 1972). The net TSP was the difference between the downwind and upwind concentrations and reflected the dust contribution from the feedlots. The peak daily total suspended particulate concentrations were usually observed at or just after sundown for 2 hours (1900 - 2200 hours local time), and ranged from 1,946 to 35, 536 Φg/m^3, averaging 14,200 ± 11,815 Φg/m^3 for 10 feedlots (Elam et al., 1971). The high peak dust concentrations in early evening result from increased cattle activity as ambient temperatures drop following daytime heating. Dust control practices in place for 2 of the 10 feedlots reduced concentrations to 1,446 and 3,153 Φg/m^3 at the peak hours. Minimum dust concentrations observed in early morning (0600 hours) were one or two orders of magnitude below the maximum and mean TSP concentrations.

At three Texas feedlots, Sweeten et al. (1988) measured net particulate (TSP) concentrations for 24 hour sampling periods. Net particulate concentrations are the downwind concentration adjusted for upwind concentration to reflect the contribution of the feedlot only. Net concentrations averaged 410 Φg/m^3 and ranged from 68 to 882 Φg/m^3. For 4 and 5 hour time intervals within the 24 hour sampling periods, the extreme range of TSP dust concentrations was 16 to 17,000 Φg/m^3.

Concentrations of total suspended particulate matter (TSP) and PM less than 10 micrometers (PM$_{10}$) aerodynamic equivalent diameter (AED) were measured, using high volume samplers, and Sierra Andersen samplers respectively (Sweeten et al., 1998). Particle size distributions of dust captured on sampler filters were measured with a Coulter Counter model TAII. Mass median diameters for high volume and PM$_{10}$ samplers averaged 9.5 ± 1.5 and 6.9 ± 0.8 Φm (AED), respectively. Three cattle feedlots (17,000 to 40,000 head capacity) in the Southern Great Plains were used in the study.

TSP concentrations measured at the same downwind locations for 5-hour time intervals ranged from 97 to 1,685 Φg/m^3 TSP and averaged 700 ± 484 Φg/m^3 TSP (Sweeten et al., 1998). Correspondingly, the PM$_{10}$ particulate concentrations ranged from 11 to 531 Φg/m^3 and averaged 285 ± 214 Φg/m^3. In all cases, these results represented the approximate center of the downwind plume at the location of the samplers (i.e., 15 meters to 61 meters beyond the feedpens). The Andersen PM_{10} sampler yielded a much higher PM_{10}/TSP ratio (0.40) than for two Wedding PM_{10} monitors (0.19) used simultaneously in several experiments (data not shown). Particles smaller than 2.5 μm (AED) represented approximately 5% of TSP.

Guarino et al. (1999) found that peak levels of dust released in a caged layer poultry building were generated by rather sudden episodes of increased bird activity triggered by noise, lighting changes, machinery, human activity, or increased temperature. Diurnal patterns were observed (highest during day and least at night). Increased total and respirable dust levels resulted in increased poultry mortality.

4. Co-Product Gases – CO_2, CH_4, and VOC

The major sources of CO_2 in swine buildings are space heating systems, animal respiration, and massive biodegradation (Lim et al., 1998). Recommended maximum allowable CO_2 levels range from 1,500 ppm to 5,000 ppm for 8-hr human exposure. Manure degradation can be a major source of methane (CH_4) and nitrogen oxides (NO_x), which contribute to the inventory of greenhouse gases (Mackie et al., 1998). Emissions of nitrous oxide (N_2O) during the nitrification/dentrification cycle can contribute to ozone depletion (Schulte, 1997). In the U.S., methane emissions from animal wastes are 15% of the total (Mackie et al., 1998; USEPA, 1992). Methane fermentation occurs in many anaerobic ecosystems, including manure storage and treatment, where the main electron acceptor, CO_2, is produced from the degraded organic substrates.

Lim et al. (1998) reported CO_2 concentrations in fan exhaust from an 880 hd grow/finish swine building with total slotted floors and tunnel ventilation with curtain side walls. Average CO_2 concentration inside was 1,060 ppm (539-2,766 ppm range), as compared to 482 ppm outdoors. Carbon dioxide production averaged 3.0 kg/pig/day (1.2-9.5 kg/pig/day range).

Safley et al. (1992) reported that the atmospheric concentration of methane (CH_4) is presently about 1.7 ppm; is increasing at the rate of 1% per year; and has more than doubled over the last two centuries. Methane contributes about 20% of the expected global warming effect, behind carbon dioxide. Animal waste contributes about 6-10% of the total worldwide anthropogenic methane emissions, and North America ranks fourth, behind Eastern Europe, Asia/Far East, and Western Europe, producing about 15% of the 28.3 Teragrams CH_4/year from animal waste. The principal determinants of methane production from animal manure are: quantity and characteristics, waste management system utilized, temperature, and moisture. Methane is produced during anaerobic decomposition, resulting from high moisture content and the absence of oxygen. Systems that bring the manure/wastewater in contact with oxygen (e.g., timely land application on fields) reduce methane production. Anaerobic lagoons were estimated to produce about one third of methane production from animal waste in North America followed by extensive ranges/pastures, liquid manure/slurry storage, open lots, solid storage, and land application.

Volatile organic compounds (non-methane reactive organic gases) are recognized as a major precursor to ozone formation. Currently, no recognized emission factors for VOC exist for

CAFOs from which states can develop reliable emission inventories and/or cost-effective mitigation measures where required.

EMISSION FACTORS: A CASE FOR ACCURACY

1. Significance of Emission Factors

Emission factors are estimates of the mass of pollutants per unit of through put or capacity. For example, the emission factor for particulate matter (PM) from a coal-fired power plant is usually expressed in units of pounds per million Btu of thermal input; a cotton gin, pounds per bale; and a cattle feedyard, pounds per thousand head per day. The annual total suspended particulate (TSP) emissions from a 1,000 megawatt power plant (30% efficient) with an emission factor of 0.03 pounds per million Btu is 1,494 tons per year; from a 20 bale-per hour cotton gin processing 20,000 bales per year with an emission factor of 3.05 pounds TSP per bale is 30.5 tons per year; and from a 40,000 head cattle feedyard with an emission factor of 280 pounds TSP per thousand head per day is 2,044 tons per year. (These example operations are well above the average size for each industry.)

Emission factors are often used in a regulatory context. The use of emission factors by EPA and state air pollution regulatory agencies (SAPRAs) can significantly impact agriculture. EPA has published estimated emission factors for many types of operations in a document referred to as AP-42 (USEPA, 1986 and 1994). However, many of the agricultural emission factors in AP-42 are proving to be incorrect and in need of updating.

EPA and SAPRAs use emission factors in air pollution regulatory process in two ways:

a. to determine the *emissions inventory* for the operation (tons per year), and
b. to estimate the *downwind concentration* that might be expected from the operation.

The annual emissions inventories are used to determine whether the operation is a “major source”. For example, any point source in an attainment area that emits more than 100 tons per year of a regulated pollutant is classified as a major source and must pay an annual emission fee to the respective state’s air fund. This fee is approximately $30 per ton of all regulated pollutants emitted.

Emission rates are the mass of air contaminant released per unit of time, calculated as (1) concentrations in air times airflow rate or (2) emission factor times capacity or through put. The emission rates of the example power plant, cotton gin and cattle feedyard listed above are 341, 61, and 467 pounds per hour, respectively based on AP-42 values (USEPA, 1986). Emission rates can be used to estimate downwind concentrations with a dispersion model.

There is another factor that impacts the air pollution regulatory process for PM. The National Ambient Air Quality Standard (NAAQS) for particulate matter is a 24-hour concentration of 150 micrograms per standard cubic meter of PM_{10}. PM_{10} is particulate matter less than 10 micrometers aerodynamic equivalent diameter (AED). In the examples listed above, it is likely that the emissions from the power plant will consist primarily of PM_{10} whereas only a fraction of the PM emitted by the cotton gin and feedyard are PM_{10}. It is generally accepted based upon studies by Texas A&M University and USDA that the fraction of PM less than 10 Φm AED is less than 50% and 25% of the total PM emitted for cotton gins and cattle feedyards, respectively.

Hence, the emission rates of PM_{10} that would likely be used for dispersion modeling downwind from a power plant, cotton gin, and cattle feedyard would be 341, 30, and 117 lbs/hr, respectively. Likewise the annual emission inventories for the power plant, cotton gin, and cattle feedyard would be 1494, 15, and 511 tons/yr of PM_{10}. These emission rates would be correct assuming that the initial AP-42 emission factor for total PM emitted was correct.

However, there are serious problems associated with either incorrect or non-existent emission factors for agricultural operations:

a. If the current AP-42 emission factors are in error, the emissions inventory will be inaccurate. An inaccurate emissions inventory will likely result in SAPRA or EPA strategies that are inappropriate, i.e. if the emissions inventory were inordinately high as a consequence of an excessively high AP-42 emission factor, excessive regulatory actions will result in a focus on an agricultural pollutant source when in fact the contribution of these sources may not be significant.
b. If the current AP-42 emission factors are in error, modeling will result in incorrect estimates of downwind concentrations, i.e. if the emission factor is too high resulting in modeled concentrations at the property line exceeding the NAAQS, additional controls will be required. In one state, modeled concentrations exceeded the NAAQS at the property line but measured concentrations were less than the NAAQS and the SAPRA indicated that they preferred the model results.
c. An even more serious problem is when no AP-42 emission factor exists. The SAPRA is likely to assume an emission factor for the agricultural operation that is incorrect or inappropriate. For example, California is in the process of permitting dairies. In the absence of an AP-42 emission factor for dairies, the assumption was made by the SAPRA that dairy operations are similar to cattle feedyards, and consequently the inaccurate PM_{10} AP-42 emission factor for cattle feedyards was used. Three mistakes were made in this assumption: (1) Dairy operations are significantly different from cattle feedyards; (2) dairy cattle do not exhibit the same aggressive behavior patterns as beef cattle on feed, thereby do not create the same level of dust emissions; and (3) the AP-42 emission factor for feedyards is excessively high.

2. Emission Factors for Cattle Feedyards and Dairies

The Department of Agricultural Engineering at Texas A&M University has been attempting to correct the AP-42 emission factor for cattle feedyards since 1992. In the latest study funded by the Texas Natural Resource Conservation Commission (TNRCC), it was determined that the appropriate PM_{10} emission factor for cattle feedyards should be 15 pounds per thousand head per day (lbs/1000hd/day). The AP-42 PM_{10} emission factor for cattle feedyards is 70 lbs/1000hd/day. The factor developed in the TNRCC study was approximately 1/5 of the emission factor listed in AP-42.

Dairy operations are considerably different than cattle feedyards but there exists no AP-42 emission factors for dairy operations. Hence, the California Air Resources Board (ARB) has required that the cattle feedyard emission factors be used. This reflects a lack of knowledge of mechanisms of dust emissions at dairies. The generation of PM_{10} in an open feedyard or open dairy lot surface is a consequence of the cattle (cows) walking on the manure pack entraining dust in air. Calves typically will be on the pavement or on pasture and will not be disturbing the manure pack. Hence, one should not include the calves in the determination of the annual PM_{10} emission inventory. The spacing of cows in dairies are typically 500 to 1200 square feet per head (ft^2/hd) in contrast to cattle in feed yards at 150 ft^2/hd. Milk cows are less active than cattle on feed yards and are on paved alleyways and milking parlors for a portion of time each day. Manure in open lot dairies must be removed frequently for milk inspection purposes whereas there is no manure removal requirement for feedyards. (Removing manure from feedyards is a management practice used to reduce PM_{10} emission rates from cattle feedyards.) Hence, it is logical to assume that the frequent removing of manure at dairies will further reduce the PM_{10} emission rate. It is likely that the emission factor for cows on dairies will be significantly less than the emission factor for cattle on feedyards. Sweeten (2000c) has estimated that the dairy cattle PM_{10} emission factor would be less than 20% of the cattle feedyard PM_{10} emission factor. If the emission factor used for the TNRCC study (15 lbs/1000hd/day) is correct, a more appropriate PM_{10} emission factor for dairies would be 4 lbs/1000hd/day.

The use of an appropriate emission factor for dairies in California is very important for the dairy industry. If the ARB were to use an inappropriate and unfair PM_{10} emission factor for dairies in California, other states will likely use similar numbers. At the same time, it is important that an accurate emission factor be used so that the impact of the emissions of PM_{10} from this project on the state's non-attainment status can be quantified.

Table 4 shows the emissions inventory calculations for four dairy projects in California using three different emission factors. The total PM_{10} emissions from the four proposed dairies range from 33 to 558 tons/year. Which annual emissions inventory figure is correct?

3. Errors in the AP-42 Cattle Feedyard Emission Factor

Parnell et al., (1999) completed a TNRCC emission inventory study in December 1999: The goal was to report "the most accurate" emissions inventory for PM_{10} from cattle feedyards in Texas. A logical approach would have been to take the emission factor multiply times the number of head of cattle in the feedyards and report the results. For example, the current AP-42 (EPA, 1995) emission factor for cattle feedyards is 280 pounds of total suspended particulate matter (TSP) per 1000 head per day (lbs/1000hd/d). Based upon work published by Sweeten et al. (1988, 1998), EPA has adopted a policy that 25% of the TSP is PM_{10}. Hence the current PM_{10}, AP-42 emission factor is 70 lbs/1000hd/d. The problem with this approach is that if the emission factor is in error, the emissions inventory will be in error. In addition, this error will be magnified with the emissions inventory calculation. An emissions inventory is calculated by multiplying the emission factor by a large number such as 3 million head (the approximate number of cattle on feed in Texas). For our TNRCC report, we reexamined the basis for the AP-42 emission factor for cattle feedyards (see Appendix A).

Emission factors are also used by modelers to estimate downwind concentrations from sources of pollution. Inaccurate emission factors can result in inaccurate estimates of downwind concentrations of PM_{10}. Inaccurate estimates of downwind concentrations can result in inappropriate, costly, and unfair imposition of control strategies.

Agricultural engineers at Texas A&M University have been conducting research with the goal of correcting the AP-42 emission factor for cattle feedyards for a number of years (Parnell, S., 1993, 1994, and 1995; Sweeten et al., 1988 & 1998; McGee, 1997). It has not been a simple task. Measurement of downwind concentrations does not directly yield emission factors. In other words, a measurement of PM_{10} does not directly reflect the emission rate or emission factor of a fugitive source. The emission factor is affected by localized meteorology, configuration of the yard, and the dispersion model used to back into the emission rate.

The current AP-42 TSP emission factor for cattle feedyards of 280 lbs/1000hd/d can be traced back to Peters and Blackwood (1977) who used the data collected by Algeo et al. (1972). The purpose of this analysis is not to be critical of the previous research, but to point out errors. By understanding what has been used for a "scientifically based" emission factor, we can better justify our approach and resulting emission factor. Peters and Blackwood used the net, downwind, 24-hour concentrations reported by Algeo from sampling at 25 California feedyards. It should be mentioned that these were the only data on net, downwind, 24-hour TSP concentrations from feedyards available at the time. California is in a winter-rainfall area, and feeds less than 5% of the nation's cattle, in contrast to the summer-rainfall climate of the Southern Great Plains, where 80% of the nation's cattle feeding activity is located. The intent of the field sampling study by Algeo et al., (1972) was to evaluate the performance of control strategies in reducing TSP and their experiments were not designed to obtain data for the development of a cattle feedyard emission factor. Accordingly, neither weather data, locations of samplers, nor feedlot orientation were reported. Several unwarranted assumptions or miscalculations were used by Peters and Blackwood (1977) in their source assessment contract report, which lead to an erroneous EPA emission factor for cattle feedlots, based solely on summer time TSP data at California feedlots. Some of these assumptions were as follows:

a. Infinite line source Gaussian model;
b. Average feedlot size of 8,000 head assumed vs. 20,000-25,000 head actual average;
c. Average animal spacing of 150 ft^2/head, which is higher than average for California feedlots;
d. Square feedyard shape factor; and
e. Erroneous coefficient in emission rate equation.

Further details and analysis are provided in Appendix A, along with an improved procedure for determining TSP emission rate from available data and to determine PM_{10} emission rate from TSP data.

4. Comparison of Emission Factors Using a Line Source (TAMU Process) and ISC Dispersion Modeling

McGee (1997) used Industrial Source Complex version 3 (ISC3) to back-calculate emission factors from cattle feedyards using the average 24-hour TSP net concentrations reported by Sweeten et al. (1988) for each of the three feedyards sampled (Table 5). He used meteorological data in his modeling and assumed the yards were square with 150 ft^2/hd. As a check to see if the above procedure would yield similar emission factors, we calculated the emission factors using the TAMU procedure (Appendix A), with the results shown in Table 4.

Note that the TSP emission factors (Table 5) were the same (97 versus 103; 50 versus 48; etc.) regardless of whether we use ISC3 or the TAMU procedure. It should also be noted that ISC3 utilizes small area sources with a subsequent integration over the area in the calculation of downwind concentration whereas the TAMU procedure utilizes a very simple line source algorithm. The grand mean concentration of 412 Φg/m^3 yielded a TSP emission factor of 20 lbs/1000hd/d (PM$_{10}$) (uncorrected for rainfall events). It would seem that the TAMU procedure could be used to determine emission factors for cattle feedyards.

5. PM Concentrations

One of the issues that was not addressed above is what net, downwind, 24-hour PM$_{10}$ concentrations would be expected from a dairy compared to a feedyard. If the dairy cows were as active as cattle on feedyards, the spacing of 1000 ft^2/head would reduce the area emission rate by 6.7 (1000 ft^2/head/150 ft^2/head). Another way of describing this is that for an area of 1000 ft^2, there would be an average of 6.7 cattle on this area for each dairy cow. Hence, the emission rate should be reduced by a factor of 6.7. Since the modeled downwind, 24-hour, TSP concentration is directly proportional to emission rate Q$_L$ (see Appendix A, Equation 1), the resulting downwind, 24-hour, TSP concentration for a dairy should be reduced by a factor of 6.7. Hence a net downwind 24-hour, TSP concentration of 412 Φg/m^3 would be 62 Φg/m^3. The net downwind 24-hour, PM$_{10}$ concentration would be 16 Φg/m^3 (0.25*62).

6. Recommendations for Correcting Emission Factors

a. The use of AP-42 for permitting cattle feedyards is inappropriate for either the cattle feedyard or dairy industries. We recommend that an appropriate emission factor for the cattle feedyard industry is 15 lbs/1000 hd/d (PM$_{10}$).
b. It is inappropriate to include the calves in the determination of the annual PM$_{10}$ emission rate for the dairy industry. Only cows spend time on the manure pack with the potential to entrain PM into the air by their hooves striking the manure pack surface. Calves are kept separate on paved areas or pasture. Hence, only the cows should be used in the emissions inventory (tons/year) calculations.
c. Dairy cows are less active than cattle in feedyards, spend a portion of time each day on paved alleyways or in milking stalls, and the open lots are “scraped” (manure removed) relatively frequently. All of these factors suggest that the PM$_{10}$ emission factor for dairies should be less than the emission factor for beef cattle in feedyards.
d. The recommended emission factor for dairies should be 4 lbs/1000hd/d (PM$_{10}$), which is 27% of the 15 lbs/1000hd/d (PM$_{10}$) we are recommending for beef cattle feedyards.

HUMAN RESPONSE AND HEALTH EFFECTS

1. Confined Animals

High levels of odorous compounds have reportedly reduced growth performance and increased susceptibility to disease in pigs in confinement (Mackie et al, 1998).

MacVean et al. (1986) found that, in feedlot cattle, incidence rates of pneumonia were greatest within 15 days of cattle arrival in the feedyard and also during autumn. The incidence of pneumonia in the 16 to 30 days on feed time frame was closely associated with the concentration of particulates of 2.0 to 3.3 Φm in diameter as well as the temperature range 10 to 15 days before the onset of the disease.

Gates et al. (2000) found that ammonia concentrations in broiler house air exceeded the poultry industry guidelines of 30-50 ppm for dietary treatment involving conventional rations with high crude protein content and for a medium crude protein treatment. Birds challenged by exposure to high levels of ammonia exhibit respiratory distress and increased incidence of certain diseases. Ammonia concentrations tend to be much higher in the boundary layer just above litter/floor level at the intake height of the birds than at human workers' height. Thus, excessive ammonia levels to the birds may not be noticed by the workers.

2. Employee Concerns

The air quality associated with confined animal feeding operations (CAFOs) may have an impact on human health. Considerable research has been reported on health effects on workers in confined swine operations where workers are indoors working with the animals. Poultry workers are affected by poor air quality also.

Von Essen and Donham (1999) reviewed published literature on health effects experienced by those who work in confined swine and poultry operations. Exposure of normal volunteers to the swine confinement environment has been shown to cause cough, dyspnea, nasal stuffiness, headache, fever, chills, nausea and eye irritation. The term asthma-like syndrome has been used to describe the cough, chest tightness, dyspnea, and wheezing which are commonly seen in animal confinement workers. Symptoms occur in approximately 25% of these workers. Chronic bronchitis is a common complaint among swine confinement workers. Approximately 25% complain of cough and sputum production characteristic of bronchitis. Episodes of organic dust toxic syndrome have been reported in up to 34% of hog farmers. Eye and throat irritation has been reported as well.

3. Affected Public

The health effects of CAFOs are not limited to the indoor CAFO environment. Wing and Wolf (1999) reported to the North Carolina Dept. of Health and Human Services on significant health effects being experienced by those who live near swine CAFOs. Increased occurrences of headaches, runny nose, sore throat, coughing, diarrhea, and burning eyes were reported. The research conducted to date shows that employees who work in the swine environment and nearby public citizens experience health effects.

CURRENT POLICY – CHARACTERIZATION & ASSESSMENT

1. Overview

Currently, there are no federal guidelines that regulate and control odors in the environment (Mackie et al., 1998). However, increasing concerns about the impact of animal/livestock feeding operations on the environment and on public health is spearheading action at the federal and state level to develop environmental protections that address waste management and odor. At the federal level, the U.S. Environmental Protection Agency and the U.S. Department of Agriculture have the authority to develop policies that apply to animal feeding operations in every state. The implementation and enforcement of national policies, however, are the responsibility of the states. Aside from national mandates, states are free to develop state-only programs as deemed necessary and in the best interest of the state. For instance, differences may arise from the pollutant(s) addressed, the degree of public outcry and the political climate of the state.

At the local level, regulatory requirements impart financial and time management burdens on farmers. For example, farmers must keep current with federal, state and local projects and regulations. Other financial and time management burdens include:

- Providing different types of information to a number of different agencies.
- Reconciling differences between agencies;
- Developing plans for formal approval;
- Implementing voluntary and mandatory measures;
- Keeping information and plans updated; and,
- Working to integrate and coordinate requirements into single, multi-faceted farm plans.

In short, new and existing environmental and conservation requirements are driving forces of the consolidation of farming operations. By integrating farm planning, farmers will be better able to meet the overhead costs associated with regulatory demands.

To date, the cost of developing and implementing Comprehensive Nutrient Management Plans (CNMPs) has not been quantified. Research is needed to evaluate the average cost per farm unit to: (1) develop the initial nutrient plan; and, (2) maintain implementation of the plan on an annual basis. Without the understanding of the costs imposed by regulatory requirements, the agricultural sector can be seriously handicapped in both international and domestic markets and in terms of its support of voluntary stewardship programs and activities. The following sections provide a description of federal, state and local policies relating to animal/livestock feeding operations across the United States.

2. Federal Policies

It is the federal government's responsibility to establish minimum national technical and regulatory standards for AFOs. Currently, the EPA regulates AFOs primarily through the Clean Air Act, the Clean Water Act, the Coastal Zone Act Reauthorization Amendments and the Safe Drinking Water Act. Other federal regulations, however, are beginning to receive more attention with regard to their application to AFOs and CAFOs. For example, recent policy guidance has focused on regulatory requirements included in the Clean Air Act, the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and the Emergency Planning & Community Right-To-Know Act (EPCRA). The USDA provides programs through the Farm Bill and other legislation to help AFOs meet performance standards through voluntary, regulatory or incentive-based approaches. On issues related to AFOs, EPA and USDA are working together to assist animal producers and the public to address environmental and public health concerns. Some of these joint efforts and other federal regulations are summarized below:

a. Draft Unified National Strategy for Animal Feeding Operation

In February 1998 President Clinton released a Clean Water Action Plan that, among other things, called for the development of an USDA-EPA national strategy to minimize the water quality and public health impacts of animal feeding operations. From this clean water initiative, a Draft Unified National Strategy for Animal Feeding Operation was developed.

The goal of EPA/USDA's AFO Strategy is to encourage AFO owners to implement strategies that minimize water pollution from confined animal feeding facilities and land application processes. To meet this goal, AFOs are expected to develop and implement a Comprehensive Nutrient Management Plan (CNMP). A CNMP includes a feed management plan, a manure handling and storage plan, a land management and manure application plan and record keeping requirements. For 95% of AFOs, a CNMP is voluntary, but strongly encouraged. For the largest 5%, however, the Clean Water Act requires AFOs to obtain discharge permits (USDA/EPA, 1998). As previously mentioned, research is needed to evaluate the cost of CNMP requirements to farmers.

b. National Pollutant Discharge Elimination System

The federal Clean Water Act provides general authority for water pollution control programs, including several programs related to AFOs and CAFOs administered under the National Pollution Discharge Elimination System (NPDES) program. The federal NPDES program is administered by EPA or any state authorized by EPA to implement the NPDES program. Currently, 43 states are authorized to administer the base NPDES program (a base program includes the federal requirements applicable to AFOs and CAFOs).[1] The NPDES program includes a permit requirement regulating the discharge of pollutants from "point" or discreet sources into the waters of the United States. Under the NPDES program, AFOs and CAFOs are defined in 40 *C.F.R.* 122.23 and Part 122, Appendix B. These regulations define an AFO as a facility that meets the following criteria:

- Animals have been, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period; and,
- Crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility.[2]

Federal regulations define a CAFO generally as an animal feeding operation that:

- Confines more than 1,000 animal units[3]; or,
- Confines between 301 to 1,000 animal units and discharges pollutants:
  - Into waters of the United States through a man-made ditch, flushing system or similar man-made device; or,
  - Directly into waters of the United States that originate outside of and pass over, across or through the facility or otherwise come into direct contact with the animals confined in the operation.

According to federal regulations, the EPA or the authorized regulatory agency can designate an AFO as a CAFO based on a determination that an operation is a significant contributor of

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[1] EPA "State Compendium: Programs and Regulatory Activities Related to Animal Feeding Operations", August 1999.

[2] 40 *CFR* 122.23(b)(1).

[3] Animal unit equivalent: 1,000 slaughter and feeder cattle, 700 mature dairy cattle, 2,500 swine each weighing more than 55 pounds, 30,000 laying hens or broilers (if a facility uses a liquid manure system), and 100,000 laying hens or broilers (if a facility uses continuous overflow watering). 40 *CFR* Part 122, Appendix B.

water pollution. This determination takes a number of factors into account, such as slope, vegetation and proximity to surface waters, based on an onsite inspection by the permitting agency. The EPA, along with USDA, states, tribes and other federal agencies will revise the NPDES permit program regulations regarding CAFOs by December 2001.

c. Feedlot Effluent Limitation Guidelines

In 1974 the EPA promulgated the Effluent Limitation Guidelines for feedlots, including the following animal sectors: beef and dairy cattle, swine, sheep, horses, broiler and layer chickens, turkeys and ducks. This guideline establishes a no discharge requirement for process wastewater, including manure from feedlots. The EPA, along with USDA, states, tribes and other federal agencies will review and revise the effluent limitation guidelines for poultry, swine, beef, and dairy cattle by December 2001. According to EPA, the revised Effluent Limitations Guidelines may require an estimated 5,800 to 20,000 CAFOs to obtain permits as compared to only about 2,000 permits issued to date (GAO, 1999).

d. Total Maximum Daily Loads

When water quality requirements are not attained, the Clean Water Act includes response actions defined as Total Maximum Daily Loads (TMDLs). TMDL requirements are implemented through the NPDES permitting program.

e. Clean Air Act

The Clean Air Act establishes a framework for the attainment and maintenance of air quality standards. In general, the Clean Air Act has two basic elements: nationwide air quality goals and individual state plans (State Implementation Plans) designed to meet the national goals. The Clean Air Act includes primary and secondary national ambient air quality standards (NAAQS) for six criteria pollutants: carbon monoxide, particulate matter, sulfur dioxide, nitrogen dioxide, ozone and lead (Table 3). The primary standards are health effect standards that are designed to protect the health of the most susceptible individuals in the population: the very young, the very old and those with respiratory problems. The secondary standards are designed to protect public welfare or quality of life. All of the air quality standards are expressed as concentration and duration of exposure. Many of the standards address both short- and long-term exposure.

f. CERCLA

The Comprehensive Emergency Response, Compensation and Liability Act (CERCLA) or Superfund, was enacted by Congress in December 1980, and amended by the Superfund Amendments and Reauthorization Act in October 1986. In general, CERCLA creates a tax on the chemical and petroleum industries and provides federal authority to respond directly to releases or potential releases of hazardous substances that may endanger public health or the environment. Historically, the fund has been used to cleanup abandoned hazardous waste sites when no responsible party can be identified. The concern in regard to CERCLA, is that it includes notification and reporting requirements for the release of certain air emissions, (CERCLA 101(10)(H)) for hazardous air pollutants such as hydrogen sulfide, ammonia and a number of volatile organic compounds commonly found in livestock manure. The EPA is expected to announce new Interim Guidance on CERCLA and EPCRA reporting requirements in August 2000. Public comment and final guidance will follow.

Heretofore, provisions concerning the release of hazardous air pollutants (HAPs) have not been applied to confined animal feeding operations as a matter of policy. "Federally-permitted releases" are exempt from reporting and notification requirements of both CERCLA and EPCRA. Nonexempt releases include: (a) accidental releases; (b) start-up and shut down releases; (c) emissions regulated only by ozone or PM standards; or (d) emissions from unpermitted or unregulated sources as per the Clean Air Act Amendments. The current reportable quantity (RQ) for both NH_3 and H_2S is 100 lbs/day, or 18.3 tons/year.

Recent EPA guidance (EPA, 1999) provides that releases from facilities that are specifically exempt from CAAA permits or control regulations are not "federally-permitted releases" and are not exempt from reporting requirements under CERCLA. This is a controversial interpretation. Issues for CAFOs include: (a) paucity of data; (b) whether standard practices for application of manure or wastewater (spreading or irrigation) are included in the exemption of "normal application of fertilizer;" and (c) whether CAFOs would be able to qualify for some relief from reporting burdens through substantiating their emissions constitute a "continuous and stable releases."

g. EPCRA

The Emergency Planning and Community Right-to-Know Act (EPCRA) is Title III part of the Superfund Amendments and Reauthorization Act of 1986. EPCRA Section 304 requires notification of hazardous air pollution emissions to EPA's National Response Center and state and local emergency planning entities when releases are greater than a set "Reportable Quantity". The Reportable Quantity of hazardous pollutants are reported in units of mass that range from one (1) pound to 5,000 pounds, depending on the pollutant. Both CERCLA and EPCRA require sources to report releases deemed to be a "continuous and stable release" of hazardous pollutants above the Reportable Quantity. CAFOs have never been aware that they are subject to the CERCLA and EPCRA reporting requirements. There is concern that the recent EPA Interim Guidance may broaden their interpretation of the regulations to include CAFOs under the continuous and stable release requirements.

h. Summary of EPA Efforts by Region

EPA Region 1 -- Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont

Relatively few AFOs are located in the New England region. To date, issues involving AFOs have been addressed at the state and local levels. Water quality impairment associated with CAFOs located in Massachusetts and Maine, however, are a growing concern to the region. Region 1 has committed approximately 10% of one (1) person's time to coordinate AFO/CAFO issues in the region.

EPA Region 2 -- New Jersey, New York, Puerto Rico and the U.S. Virgin Islands

Region 2 is developing a regional AFO/CAFO program including a permit program for CAFOs in Puerto Rico.

EPA Region 3 -- Delaware, Maryland, Pennsylvania, Virginia, West Virginia and Washington D.C.

The primary AFO issues in Region 3 are related to poultry and hog facilities. To date, efforts in Region 3 have focused on inspections and public outreach. Region 3 has committed 3.0 FTEs to CAFO/AFO issues.

EPA Region 4 -- Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina and Tennessee

Region 4 is developing a strategy to address AFOs. It is anticipated that the strategy will incorporate both the objectives of the Clean Water Act and components of the USDA/EPA Joint Strategy for AFOs. The region has developed an enforcement strategy that relies on state referral of cases, citizen complaints and the review of state regulatory files. The Region has assigned 4 FTE to AFO/CAFO issues, including 1.5 FTE for program coordination and permitting and 2.5 FTE for enforcement.

EPA Region 5 -- Illinois, Indiana, Michigan, Minnesota, Ohio and Wisconsin

Regional efforts focus on evaluating and developing state programs, advising producers of NPDES requirements and conducting inspections. Region 5 has dedicated 0.5 FTE for permitting and 0.5 FTE for enforcement and compliance assurance.

EPA Region 6 -- Arkansas, Louisiana, New Mexico, Oklahoma and Texas

Region 6 enacted a CAFO general permit in 1993 that requires a pollution prevention plan and adoption of best management practices that address: manure and wastewater management, nutrient management, and groundwater protection. It does not directly address air quality issues. Region 6 developed a multimedia AFO workgroup to discuss common issues and respond to requests for information. Region 6 also adopted a Cumulative Risk Index Assessment (CRIA) model that indirectly addresses potential impacts of CAFOs within a designated watershed or airshed. Region 6 has committed 2 FTE to general CAFO activities and 0.75 FTE for permitting and 2 FTE for enforcement.

EPA Region 7 -- Iowa, Kansas, Missouri and Nebraska

Region 7 is very active in addressing AFO/CAFO issues. All four Region 7 states have strong CAFO programs dating back to the early 1970s. Because these states have strong programs in place, Region 7 has not independently pursued regulatory activities related to CAFOs in the region until taking an enforcement action in April, 2000 against seven commercial swine operations owned by a corporate swine operation in Missouri. This Notice of Violation (NOV) is for air pollution violations of the Clean Air Act and the Missouri State Implementation Plan. In general, the enforcement action addresses violations of pre-construction and operating permit requirements and for air pollution emissions greater than de minimis levels (PM_{10} and H_2S) included in Missouri's SIP. Region 7 devotes approximately 1 FTE to AFO/CAFO activities.

EPA Region 8 -- Colorado, Montana, North Dakota, South Dakota, Utah and Wyoming

In Region 8, the states are responsible for issuing permits, conducting inspections and carrying out enforcement actions under the NPDES program. Region 8 only gets involved after receiving a specific complaint.

EPA Region 9 -- Arizona, California, Hawaii, Nevada and other territories of American Samoa and Guam

Region 9 is working with these states to develop and implement state-specific strategies for animal feedlots. Region 9 has an active outreach, inspection and enforcement program. 3.0 FTE are devoted to enforcement and compliance assistance and 0.3 FTE for permitting.

EPA Region 10 -- Alaska, Idaho, Oregon and Washington

Region 10 has adopted a watershed approach with a focus on water quality impairment, to address AFO issues. Region 10's program consists of three components: (1) permitting, (2) inspections and (3) enforcement. Six (6) FTEs are devoted to AFO/CAFO issues in Region 10.

3. Recent State Policy Developments

State and local governments often have the responsibility of implementing federal programs. For example, 42 states and the Virgin Islands are authorized to implement the NPDES permit provisions of the Clean Water Act (USDA/EPA, 1998)

State programs and AFO requirements vary from state-to-state. Listed below is a summary of some of the notable activities relating to AFOs at the state level:

Alabama

In 1998, Alabama developed a Memorandum of Agreement outlining the responsibilities of state and federal regulatory agencies as they relate to AFOs and CAFOs. In general, Alabama administers an AFO/CAFO program that requires proper management of waste collection, storage, transport, disposal, land application and siting buffers. Currently, the state is considering moving toward a phosphorous standard that would be based on NRCS standards and guidelines to determine appropriate agronomic rates. Water quality is regulated through a state administered NPDES program**.**

Alaska

The state of Alaska does not have an EPA authorized NPDES program. Federal CAFO rules apply.

Arkansas

In 1990 Arkansas implemented a short moratorium on construction of new hog confinements. Two years later, Arkansas passed Regulation 5, the state's primary guidance for regulating large hog operations. Regulation 5 requires all confined animal waste facilities that use liquid waste handling systems to obtain a state permit. For new facilities, permit applicants must publish a notice in a county newspaper describing the type of facility to be constructed, the type of waste to be generated, the waste handling treatment to be used and a legal description of the property. Anyone who objects to the facility is provided the opportunity to lodge a formal objection notice with the Arkansas Department of Pollution Control.

In general, Regulation 5 prohibits the land application of animal waste when soil is saturated, frozen, covered with ice or snow, or when significant precipitation is expected within 24 hours. The rule also prohibits the application of manure on land with a slope greater than 15% and within 100 feet of streams, 50 feet of property lines, or within 500 feet of neighboring buildings. A waste management plan that describes application rates for manure and contains an annual report must be submitted to the Department of Pollution Control by all permitted facilities. Issues associated with air quality, odor in particular, are not addressed by Regulation 5. In addition to Regulation 5, all managing owners and operators of a facility must complete a waste management and odor control training program.

The Arkansas Department of Environmental Quality has issued permits for AFOs since 1970 under the authorities contained in the Arkansas Water and Air Pollution Control Act. Arkansas also sets minimum standards for liquid waste management systems and for land application of animal waste.

Arizona

Arizona is not authorized to administer a NPDES permit program. General permits for CAFOs are issued by EPA Region 9. The Arizona Department of Environmental Quality administers a voluntary non-point source program to minimize the impacts of CAFOs on surface and ground water. Air regulations are applied according to the federal Clean Air Act.

California

California issues general CAFO NPDES permits. Permits for storm water runoff discharges maybe required prior to construction of new CAFOs. The state of California is working with EPA Region 9 to develop a statewide strategy to address animal waste.

California has permit programs regulating the activities of confined animal facilities. California has their “Porter Cologne Water Quality Act,” regulating the activities of discharges and implements the National Pollutant Discharge elimination System (NPDES). The regulations establish construction standards, monitoring standards, establish standard for unauthorized release, and reporting.

The State legislature established the Water Resources Control Board (SWRCB) to administer the regulatory programs. The SWRCB to provide comprehensive protection for California’s waters. The Regional Water Quality Control Boards issue discharge permits for all confined animal facilities.

Also, there is a piece of legislation unique to California, the California Environmental Quality Act (CEQA), which allows for public participation in the permitting process. Results of CEQA have been the establishment of standards more stringent than Federal regulations for the mitigation of air and water discharges from agricultural operations.

Colorado
Prior to 1999, Colorado did not regulate agricultural operations. In November 1998, Colorado voters overwhelmingly approved (by 64%) an amendment to the Colorado Revised Statutes pertaining to odor and water quality. Specifically, Amendment 14 requires the state air and water quality commissions to regulate housed commercial swine feeding operations. In terms of air quality, the purpose of the regulations is to minimize odorous emissions from all aspects of swine operations that are capable of housing over 800,000 pounds of swine at any one time (Colorado Regulation No. 2). In general, the regulation requires facilities to obtain a permit to operate, to install covers on all anaerobic lagoons, to adhere to mandated setback requirements and land application bans and to minimize odor in swine confinement structures through the implementation of odor control technologies and work practices.

In Colorado, permits are not required or issued, but CAFOs are required to operate as no discharge facilities under a self-implemented NPDES regulation. AFOs not defined as CAFOs need to meet BMPs prescribed by the Colorado Water Quality Control Commission. New, reconstructed or expanded CAFOs must submit a Manure Process Wastewater Management Plan to the state.

In April 2000, Colorado adopted legislation strengthening Colorado's "Right to Farm" law. The new law boosts the "First In Time - First In Right" standard for agriculture. Under this new legislation, the agricultural operation cannot be deemed a public or private nuisance if the operation was in existence prior to the development around it.

Connecticut
Connecticut AFOs are exempt from air quality regulations if they are following BMPs. Any activity on wetlands falls under state/federal regulations. Connecticut does not use the federal animal unit thresholds, but regulates on a case-by-case basis.

Delaware
CAFOs must follow state and federal regulations regarding air quality. Delaware uses voluntary programs to encourage the use of BMPs in regard to manure management.

Florida
The state of Florida administers a CAFO rule that follows the federal regulations. State permits require zero discharge and construction and operation permits are required. Permits are required for dry system poultry operations and some liquid manure systems. CAFO determinations for facilities with 1,000 or fewer animals units are made on a case-by-case basis.

Georgia
Georgia mandates a “bad actor” bill that allows EPA to deny permits to operators with poor compliance records in or out of the state. AFOs in Georgia are required to be no-discharge systems and NPDES permits are not issued. A voluntary program encourages the agricultural community to practice voluntary pollution prevention.

Hawaii

Oversight of CAFO issues is based on a complaint driven process. A guidance policy for livestock waste management addresses wastewater concerns related to CAFOs.

Idaho

The Idaho Department of Environmental Quality reviews all plans for new or modified waste treatment disposal facilities before construction. Dairies, in particular, are regulated by the Idaho Department of Agriculture through pollution prevention MOU and Wastewater Management Guidelines. AFOs that fall under the federal CAFO regulations are covered by a general NPDES permit issues by EPA Region 10. In general, the rules are designed to protect water quality through the abatement of water pollution from agricultural sources through the use of Best Management Practices.

Illinois

Since 1979, the Illinois EPA has operated a livestock waste management program that provides for inspection of livestock facilities throughout the state. In 1996, citizen groups pushed for tighter rules for all new hog production facilities through the development and approval of a site development report. Although the citizen group bill did not pass, a Livestock Management Facilities Act was adopted in 1996. The Act was revised in 1998 to include rules pertaining to livestock animal management.

The Livestock Management Facilities Act and associated rules require owners of new lagoons to show evidence of financial responsibility in case of closure of the lagoon. In addition, all operations over 7,000 animal units (about 17,500 full-grown hogs or 233,333 feeder pigs) are required to prepare and submit a manure management plan to the Illinois Department of Agriculture. Other requirements include a setback distance of one mile between an operation of 7,000 animal units and a populated area, or 2 mile between an operation and a residence. Operations between 2,400 and 17,500 hogs would have to maintain, but not submit, a general waste management plan. All operators of over 1,000 animal units must attend a training session and pass a written test in manure management.

Indiana

The Indiana Confined Feeding Control Law requires CAFOs to receive approval from the Indiana Department of Environmental Management of plans for waste treatment facilities. CAFOs must also follow water quality regulations. No air quality or other environmental regulations address CAFOs.

Iowa

The Iowa Department of Natural Resources implemented a livestock-permitting program in 1972. Then, in 1978, the Iowa NPDES program was implemented. The discharge of manure directly into state waters is prohibited by Iowa’s Livestock Regulation Act – “manure law” that was adopted in 1995. More recently, the Department of Natural Resources proposed rules requiring producers to inject manure rather than spread it, and to prohibit the application of manure on frozen or snow-covered ground. The rules would also expand the number of operations who need to obtain permits.

Kansas

The Kansas Department of Health and Environment has regulated feedlots since 1968. Historically, regulations have focused only on large cattle feeding operations. In 1994, however, the Kansas legislature passed a law requiring operations over 300 animal units to register with the state and to establish a setback distance of 4,000 feet between an operation over 1,000 animal units and a residence. Then, in April 1998, the state legislature passed a new swine facility environmental regulation package. Regulations are currently being developed.

Kentucky

In 1980 Kentucky enacted legislation to deal with nuisance actions and the ability of local governments to abate agricultural nuisances. The intent of this legislation was to protect existing farms from being pushed out of existence from growing suburban areas. The scope of this legislation was expanded in 1996 to include protections against legal actions against agricultural operations.

Kentucky has a Swine Waste Management Permit program that requires all new swine feeding operations and existing operations that increase capacity to more than 1,000 animal units to obtain a permit.

Louisiana

CAFOs in Louisiana are issued individual permits under a state authorized NPDES program administered by the Louisiana Department of Environmental Quality.

Maine

No large AFOs exist in Maine and no CAFO permits have ever been issued. Currently, however, Maine is developing legislation to define CAFOs and to establish regulatory requirements for CAFO facilities.

Maryland

The Maryland legislature passed a Water Quality Improvement Act in 1998 that mandates nutrient management for all Maryland farms. A cost share program helps farmers meet installation costs for BMPs to protect water quality. Maryland is authorized to administer the NPDES program and has completed a draft general NPDES permit for CAFOs that is being reviewed by EPA Region 3.

Massachusetts

There are no large CAFOs in Massachusetts. The state, however, is authorized to administer a NPDES program and is working with EPA Region 1 to develop a permit template for CAFOs.

Michigan

Michigan has a Right-to-Farm Act that outlines Generally Accepted Agricultural Management Practices. This guidance document addresses siting of operations, designing waste disposal systems and the application of waste to agricultural lands.

Minnesota

Minnesota established a Feedlot Program in 1971 to address pollution from feedlots. The program is administered through the Minnesota Pollution Control Agency and the Water Quality

Division. State permits are issued in one of three forms: Certificates of Compliance; Interim Permits; or Five-year Feedlot Permits.

In 1997 the Minnesota legislature adopted a law requiring the Minnesota Pollution Control Agency to establish a state hydrogen sulfide standard. The standard for hydrogen sulfide is a 30-minute average of 30 parts per billion (ppb) twice in five days or a 30-minute average of 50 ppb twice a year. In addition, the law includes funds for monitoring emissions around the lagoons. Farmers were recently granted a 17-day grace period each year to agitate manure storages for manure application.

The Minnesota Pollution Control Agency is in the process of amending its animal feedlot rules. If successful, feedlots would be required to obtain a series of general permits, all addressing slightly different circumstances.

Missouri

In 1995 and 1996, Missouri experienced numerous manure spills that prompted the state to place a temporary moratorium on granting permits to corporate hog operations. Shortly thereafter, the Missouri legislature adopted a law requiring operators to conduct facility inspections twice a day on hog barns, sewage pipes and lagoons. The legislation also established a setback requirement for animal units of over 1,000 in number of 1,000 feet. An operation of over 7,000 animal units must be 3,000 feet from a residence. In addition, a new operation is required to notify adjoining property owners of proposed construction plans.

Currently, the Missouri Department of Natural Resources, Air Pollution Control Program lacks regulatory authority over AFOs because air quality regulations pertaining to odor are exempt from Missouri laws. In 1997, however, the Missouri Attorney General issued a petition to the Missouri Air Conservation Commission to amend the Missouri’s odor rule by removing the odor exemption. The Commission formed a workgroup to address the odor issue. The end result of the workgroup was to develop rule language, although a formal rule was not agreed upon by the entire workgroup.

Missouri administers the NPDES permitting program through the use of a general permit process. In general, all CAFOs must receive a NPDES permit to be covered under Missouri’s general permit requirements. CAFOs are classified under four different classification schemes based on the number of animal units. The classification dictates the permit and/or BMP requirements.

Mississippi

In 1998, the Mississippi legislature issued a two-year moratorium on permits from CAFOs submitted after February 1998. All CAFOs are subject to the federal NPDES permitting requirements. CAFOs outside the federal definition must submit a wastewater treatment/disposal worksheet and have an on-site inspection to ensure compliance with siting criteria.

Montana

The state of Montana mirrors the federal NPDES program.

Nebraska

Nebraska began its livestock-permitting program in 1972. NPDES permitting began in 1974. In April 1998, new legislation was passed that requires the state to develop a permit fee system, financial assurance plans and a training program for land application of waste. The state is currently developing a general CAFO permit.

Nebraska law permits counties to develop comprehensive plans and zoning ordinances that pertain to agriculture. Public hearings are being held statewide to determine what improvements are needed in state environmental regulations to address animal feeding operations in the state. Nebraska has a constitutional restriction on corporate farming.

New Hampshire

There is only one CAFO in New Hampshire and no NPDES permits have been issued.

New Jersey

There are no CAFOs in New Jersey. The state does, however, have a state NPDES program and specific criteria for CAFOs.

New Mexico

New Mexico is not a NPDES delegated state. EPA Region 6 issues general permits to CAFOs in New Mexico. The state issues ground water discharge permits through the New Mexico Water Quality Act.

New York

New York regulates CAFOs under a state administered NPDES program. In 1996, the New York Department of Environmental Conservation formed a technical CAFO workgroup to examine legal, regulatory, policy, environmental and economic issues associated with CAFOs. The group developed a series of four options from a totally voluntary program to implementation of the EPA CAFO regulations. General CAFO permits are required under the EPA-type programs. The state has issued a “Guide to Agricultural Environmental Management in New York State” as guidance for the voluntary program.

North Carolina

In March 1997 North Carolina adopted a two-year moratorium on all new construction of hog operations larger than 200 head. North Carolina law gives counties the authority to zone and regulate hog operations over 600,000 pounds of swine (about 4,000 finishing hogs) through a general permitting process. A county is not permitted to exclude hog operations from a zoned area.

The law establishes a number of setback requirements: 1,500 feet between an operation and a home; 2,500 feet between an operation and a public area; 500 feet between an operation and a property line; and 500 feet between an operation and a well (with some exceptions allowed). In addition, manure cannot be spread within 75 feet of a property line or waterway. The law does include citizen suit provisions and notification requirements for new or modifications to facilities.

With respect to other AFOs, the North Carolina Division of Water administers a waste management permitting system. Together with permit requirements, operators are required to complete mandatory training and receive certification. North Carolina also administers an Agriculture Cost Share Program for nonpoint source pollution control. This program pays farmers up to 75% of the average cost of implementing approved BMPs and provides technical assistance to landowners.

North Dakota

The North Dakota State Department of Health administers state regulations regarding CAFOs. Permits are required for all CAFOs that handle 200 or more animal units and all feeding operations located in a three-year flood plain that have 100 or more animal units. North Dakota defines CAFOs as (1) any livestock feeding handling or holding operation in an area not normally used for pasture or growing crops where livestock waste accumulates, or (2) where the space per animal is less than 600 square feet.

Since 1987 (as amended in 1990) North Dakota passed general regulations to address odorous air contaminants. The restrictions on odorous air contaminants are based on general provisions pertaining to the discharge of objectionable odors in ambient air. Exemptions apply for land application purposes and during spring turnover of anaerobic lagoons.

Ohio

The Ohio EPA administers the Animal Waste Pollution Abatement Program. The Ohio Department of Natural Resources permits livestock operations over 1,000 animal units. The Division of Soil and Water addresses operations smaller than 1,000 animal units. Several voluntary programs exist at the state and university (Ohio State University) level to help farmers address pollution problems. A general NPDES permit is administered by the state.

In 1996 the Ohio General Assembly considered, but did not approve, legislation that would give townships the authority to vote on whether a large livestock operation could be built in the county. Other legislation has been introduced, but not adopted. In general, this legislation has recommended the establishment of a permit system based on water quality testing for all large livestock management facilities (25,000 hogs, 10,000 beef cattle and 1 million chickens).

Oklahoma

Historically, only water quality laws in Oklahoma placed restrictions on large animal feeding operations. Under the water quality rules, large operations must apply for an Oklahoma CAFO License. The law applies to cattle, swine, sheep, horses and poultry by monitoring waste management programs.

On September 1, 1997, a bill passed the Oklahoma legislature requiring operations with over 5,000 head of hogs to obtain a permit and provide detailed information about the operation and its management. The law also requires citizen notification within one-mile of a proposed operation, a pollution prevention plan, a public hearing (optional), annual soil testing, record keeping, and annual, unannounced inspections of operations. Setback requirements are required depending on the size of the operation and whether it is located in the eastern or western part of the state.

In 1998 a poultry bill passed the legislature requiring poultry operations to register with the state. In addition, the bill sets waste management and soil testing requirements, et al.

Oregon

The Oregon Department of Environmental Quality began permitting CAFOs in early 1980. Since 1993, the state Department of Agriculture has run the program. Under Oregon's law, farmers are required to obtain permits to construct, install, modify or operate CAFO wastewater containment or disposal systems. CAFOs are exempt by state law from air quality regulations.

Pennsylvania

Pennsylvania regulates CAFOs through state water quality and nutrient management regulations. CAFOs are exempt from air quality regulations. The state administers its own NPDES program, but has not issued any general or individual permits to date.

Rhode Island

Rhode Island uses a watershed-based approach to regulate CAFOs. Pollution problems are addressed on a case-by-case basis.

South Carolina

South Carolina has been regulating AFOs since the mid-1960s. Permits are required for the discharge of pollution to surface or ground water. In 1996, the South Carolina Confined Swine Feeding Operations Act was adopted. The regulations apply to operations exceeding 3,000 head of hogs and establish setback requirements for lagoons between waterways and neighboring residence. Nuisance odors are also included in the rules. In addition, the regulations include specifications for the construction of lagoons and the land application of manure.

The state is authorized to administer a NPDES program utilizing either a general or individual permit system. Waste management plans are required by law, and any discharge of effluent to surface water is a violation of state law, except in cases of natural disasters or social upheaval.

South Dakota

In 1997, the South Dakota legislature passed legislation that requires additional permitting requirements for new CAFOs constructed over shallow aquifers. This legislation requires CAFOs to pay an annual fee to cover regulatory costs. It requires the Department of Natural Resources to develop an inspection and enforcement program, and it provides the state with the authority to deny permit applications for “bad actors”.

In 1998, the citizens of South Dakota placed a constitutional amendment on the ballot to ban all corporate farming by non-family farmers. This action kept some large corporations from moving into the state. Basically, this legislation allows the state to hold negligent livestock owners liable for environmental pollution and establish an environmental cleanup fund for spill and releases from AFOs.

In South Dakota, counties have the authority to regulate the siting of agricultural operations. The state has adopted a general permit requirement for hog operations over 1,000 animal units.

Under the general permit, facilities have to conduct annual soil tests; apply stored manure within 270 days; publish a notice in the local newspaper of any pending permit applications; limit the spreading of manure on frozen ground; and, require operators to complete manure management training.

Tennessee

State law exempts agricultural practices from regulation, except for point source discharges from confined operations. Tennessee is authorized to administer a NDPES program and a general permit for CAFOs (301 to 1,000 animal units) has been developed. Larger CAFOs are required to get individual permits.

Texas

The Texas Natural Resources Conservation Commission (TNRCC) regulates wastes from CAFOs. Under state law, the Texas Water Code and the Texas Clean Air Act authorizes TNRCC to administer the CAFO program. These rules require all CAFO operators to collect, store and handle animal waste and control dust and odor.

TNRCC put together an Agricultural Team to help CAFOs implement BMPs for managing animal waste. The agency also manages a Dairy Outreach Program that includes animal waste management training.

In Texas, EPA Region 6 administers the NPDES program. In some instances, Texas can issue state permits-by-rule pertaining to air and water quality for CAFOs. Every CAFO, however, is required to submit a pollution prevention plan to address discharges to state waters.

CAFOs in Texas have been regulated under strong programs as a point source for water quality purposes since the early 1970s, first by individual permit then since 1987 under one or more versions of state regulations. In addition, USEPA Region 6 imposed a comprehensive general permit on CAFOs in 1993 that requires adoption of best management practices (BMPs) for water quality protection and a pollution prevention plan (PPP), which include some measures that can improve air quality in a corollary fashion. Upon EPA delegation of authority to issue NPDES permits in 1998, the Texas Pollutant Discharge Elimination System (TPDES) rules were adopted in July 1999 and require application of BMPs and PPPs for both water and air quality. For air quality protection, Texas requires an operating permit for CAFOs with more than 1,000 head of livestock or the equivalent. Fundamentally, for air quality protection, Texas operates under the public nuisance rule. A Right to Farm Act was enacted in 1991 as well, limiting private lawsuits filed more than one year after an operation has been in existence. Texas has no specific odor intensity criterion nor a preferred monitoring method. The current (1999) TNRCC Subchapter B NPDES regulations regarding CAFOs have a quarter-mile or a half-mile setback distance requirement, unless they have an odor management plan and depending on written permission from neighbors.

Texas also adopted a hydrogen sulfide rule that became effective in 1974. The H_2S rule prohibits hydrogen sulfide emissions from a source or multiple contiguous sources from exceeding specific H_2S levels averaged over a 30-minute sampling period. Net ground-level concentrations are not allowed to exceed 0.08 ppm H_2S (80 ppb) if they affect residential, business, or commercial properties, nor 0.12 ppm H_2S (120 ppb) if they affect other property uses, "such as industrial property, vacant tracts, and rangelands not normally occupied by people." General industry compliance with these rules was determined by TNRCC monitoring in 1998 and 1999.

Utah

In Utah, CAFO permits are administered by two agencies: the Utah Department of Environmental Quality and the Utah Department of Agriculture and Food. While Utah administers a NPDES program, swine facilities are not subject to NPDES permits, unless a facility has a point source discharge to surface waters of the state.

Virginia

There are no air quality regulations affecting CAFOs. The Virginia Environmental Quality administers the NPDES program under the authority of the federal Clean Water Act. Virginia issues general and individual no-discharge permits to CAFOs that are 300 animal units or more. No NPDES permits have been issued to CAFOs to date.

Vermont

The Vermont Department of Agriculture is working with the Vermont Department of Environmental Conservation to develop a CAFO program based on federal CAFO requirements and new state legislation. At present, there are neither specific rules nor air quality regulations for CAFOs. To date, Vermont has not issued a NPDES permit.

Washington

The Washington Department of Ecology is responsible for regulation of CAFOs under the state Water Pollution Control Act. Dairies (larger than 300 animal units), in particular, are subject to regulatory requirements including permitting, nutrient and waste management planning.

West Virginia

CAFOs in West Virginia are subject to the federal NPDES permit program. Voluntary educational programs are used to address concerns with fertilizers and manure issues affecting groundwater.

Wisconsin

Wisconsin CAFOs have been regulated since 1984 by the Wisconsin Department of Natural Resources under the state's NPDES program. Wisconsin law requires AFOs over 1,000 animal units to obtain a permit and file an animal waste management plan. Since 1995, about half of the state's counties have animal waste storage ordinances, but recent proposals are trying to limit local authority.

Wyoming

The Wyoming Department of Environmental Quality regulates wastes from AFOs through the NPDES, water and wastewater and solid waste programs. In 1997 Wyoming adopted regulations applicable to facilities over 1,000 animal units. The law requires manure management plans to address both water and odors. Setback requirements of one mile between an operation and a residence, school or town, or ¼ mile between an operation and a domestic well or waterway are included in the regulations. The Wyoming Department of Environmental Quality is drafting and implementing the law.

The state of Wyoming has entered into a Memorandum of Understanding with USDA-NRCS to assist small AFOs with design and construction of whole-farm waste management systems. The plan developed in cooperation with NRCS can be accepted in lieu of a construction permit for waste treatment systems (USEPA, 1998). Individual permits are required for CAFOs larger than 1,000 animal units.

CURRENT TECHNOLOGIES TO ADDRESS ODOR PROBLEMS

1. Approaches: An Overview

Many technologies for control of odor and odorants from CAFOs have been developed over the last 3 or 4 decades. Some of these technologies have been evaluated to the point of proof of efficacy, but most have not been evaluated properly or systematically. Moreover, development of odor control practices has largely been approached as a single-technology that only partially addresses the issues. By contrast, the CAFO industry would be better served, and the neighboring public better protected, by utilizing a more holistic approach that takes into account (a) potential sources within a CAFO/feeding systems; and (b) potential approaches and methods of odor/odorant control that are applicable to that feeding system or source. Table 6 represents a matrix of potential control approaches and the odor source or location, within CAFOs/feeding facilities and their associated manure treatment/storage and land application system (Sweeten, 2000c).

Technologies presently exist to produce pigs with an acceptable degree of odor control (Miner, 1995). Larger operations generally have greater odor potential. There are costs associated with higher degrees of odor control; not all locations require the same degree of odor control; and requirements may change over time.

Specific measures have been devised to reduce odor from livestock facilities (Miner, 1974, 1975b, and 1995; Barth et al., 1984; ASAE, 1999a; Sweeten, 2000b; Sullivan et al., 1999). These measures generally fall under four broad approaches: (1) ration manipulation, (2) improved manure collection and treatment, (3) capture and treatment of odorous gases, and (4) enhanced dispersion. These primary approaches are discussed in the following sections:

2. Diet Effects on Odors

Zhu et al. (1999) confirmed through an extensive literature review that most odorous compounds in swine manure are produced from processes involved in protein decomposition; and thus, reducing the protein content in the manure should help reduce swine manure odor. In recent years, ration changes to alter protein composition or feed additives has received considerable attention (Harrison, 2000). James et al. (2000) determined a 28% reduction in ammonia emissions from dairy heifers by feeding a reduced-nitrogen diet (9.5% crude protein) as compared to a normal 11.0 crude protein diet. Ammonia volatilization was measured on in-vitro manure slurry samples, with 90% of the total measured within the first 26 hours. Ammonia volatilized represented 42% and 53% of the initial manure nitrogen for heifers and calf experiments, respectively. Estimated daily NH_3 volatilization (g/day) was clearly related to the daily nitrogen intake of heifers (g).

Imbalances of the C:N ratio in intestinal systems of pigs, or during anaerobic digestion will produce increased levels of malodorous compounds and reduced efficiencies of nutrient and energy utilization in the pig (Drochner, 1987). Many of the odorous compounds are associated with amino acid degradation, resulting in ammonia (NH_3), amines, skatole, indole, p-cresol, aliphatic aldehydes, hydrogen sulfide (H_2S) and other sulfur-containing compounds. Regulating the sources, levels and efficiency in utilization of specific carbohydrates, N and S compounds to minimize amino acid degradation in the pig should reduce odors and improve the environment for the pigs and humans working in the facilities.

Results from a two-year study showed a 28% reduction in NH_3-N content and emissions from fresh manure when feeding pigs 3 percentage units less crude protein diets supplemented with essential synthetic amino acids (Sutton et al., 1997). Volatile fatty acid concentrations and other organic compounds emitted in air were also reduced. Even greater reductions (by 58%) of NH_3 release and other odorous compounds were observed in anaerobically stored manure from this trial. Adding 5% cellulose to the amino acid supplemented low protein diet reduced NH_3 emission 46% (67% on a dry matter basis) from fresh manure. The pH of fresh manure was reduced 1.5 units (from 8.0 to 6.5) with the addition of cellulose and VFA's were higher in fresh manure contents (Sutton et al., 1999). In a follow-up study (Sutton et al., 1998), reducing the sulfur amino acids and crude protein (5%), by adding essential amino acids to the diet reduced ammonia and odor emissions, total VFA (by 57%) and total nitrogen excretions 45% in fresh manure. The pH of the urine was reduced 2.0 units which significantly reduced ammonia emissions. Ammonia emission was reduced by 48% in anaerobically stored manure. In addition, there was evidence that reducing the sulfur containing amino acids and removing the sulfur trace mineral sources from the pigs diet reduced the sulfur containing odors (dimethyl sulfide, dimethyl disulfide, dimethyl trisulfide, carbon disulfide, etc.) by 63%.

Group feeding studies at Purdue University (Kendall et al., 1998) verified that reducing crude protein (CP) (4.5%) and supplementing the diets with synthetic amino acids can effectively reduce ammonia and odor emissions from confinement buildings. There were 40% reductions in aerial and pit ammonia concentrations with pigs fed a reduced crude protein diet (RCP). Along with this, there was a 40% lowering of aerial hydrogen sulfide concentrations and the odor dilution ratio decreased by 30% when pigs were fed the RCP diet. In another study (Kendall, et al., 1999), reducing the dietary CP (by 2.7%) and adding 10% soybean hulls to diets (RCPF) lowered aerial ammonia (by 41%), pit TN (by 23%), pit ammonia (by 29%), pit pH (by 0.3 units), and aerial hydrogen sulfide levels (by 26.5%). Animal performance (weight gain and feed efficiency) was the same between the control and low protein and fiber diet in male castrates, but female did not perform as well on the low protein and fiber diet. Carcass quality was similar for all pigs except for a reduced backfat in male castrates fed the RCPF diet compared to those fed the control diet.

Research in The Netherlands showed a 40% reduction in ammonia emission with a 4% reduction in dietary crude protein and additional ammonia reductions by limiting synthetic amino acids (Achterstraat and Spoorenberg, 1997). Non-starch polysaccharides in fibrous feed ingredients (dried sugar beet pulp, soybean hulls, wheat bran) have been shown to enhance energy balances, reduce nitrogen excretion in urine and pH of manure resulting in reduced ammonia emissions (Canh et al., 1998). Of the fiber sources studied, soybean hulls and sugarbeet pulp had the greatest effects on reducing ammonia emissions.

The addition of high dietary concentrations of copper to weaning and growing pigs has been shown to alter microflora patterns in the feces Goihl (2000), giving rise to the theory that subsequent odor of manure may be altered. Copper sulfate serves an antibiotic function in pigs, and from 75-90 % of the consumed copper is excreted. Goihl (2000) cited experiments to determine the effects of dietary copper concentration and source on odor characteristics of swine manure. Dietary copper levels and sources fed to both nursery pigs and growing-finishing pigs were: copper sulfate – 10 ppm (control), 66 and 225 ppm; and cupric citrate – 33, 66, and 100 ppm. Odor was evaluated by 10 trained odor panelists who sniffed the headspace of laboratory containers containing the treated manure samples. Panelists furnished qualitatively ratings on 0-8 point scales of: odor intensity (none to maximal), irritation intensity (none to maximal), and odor quality (extremely pleasant to extremely unpleasant). Results of Experiment I that included the antibiotic carbadox in all rations, showed that odor intensity and irritation intensity both decreased significantly in manure from nursery pigs fed 225 ppm copper sulfate and 66 or 100 ppm cupric citrate, as compared to the control treatment (10 ppm copper sulfate). Likewise, in growing pigs, treatments of 66 and 225 ppm copper sulfate and 66 and 100 ppm cupric citrate significantly reduced odor and irritation intensity, and all treatments improved odor quality over the controls diet. However, when the antibiotic carbadox was removed from all rations in Experiment II, copper sulfate at higher levels than the 10 ppm control (i.e., at 66 and 225 ppm) did not improve odor intensity, but all three levels of cupric citrate did improve (reduce) odor intensity. Odor quality was improved by 225 ppm copper sulfate and by 33, 66, and 100 ppm cupric citrate, but irritation intensity was not affected by any of the 5 experimental treatments. In summary, 66 – 100 ppm cupric citrate was as effective as 225 ppm copper sulfate in improving odor parameters in swine feces, and can be considered a tool for odor management planning for swine. However, it should be cautioned that the pork and poultry producers' needs to feed high levels of copper (e.g., 250 ppm) have decreased in the last few years as sanitation conditions have improved, and ruminants do not tolerate high levels of copper in the diet which can lead to copper toxicity in cattle or sheep at levels exceeding as little as 20-25 ppm (Greene, 2000).

The reduction of substrates for anaerobic activity is an approach to reducing odor emissions (Baidoo, 2000), and includes various feeding strategies such as: reduced nitrogen intake, phase feeding, repartitioning agents, improved animal genetics, and various feed additives. Some of the feed additives include: sugar beet pulp, soybean hulls, Jerusalem artichoke, zeolite, and yucca extracts. Altering the dietary electrolyte balance resulting in lowered pH may be a means or reducing ammonia emissions at least.

3. Manure Treatment for Odor Control

Manure treatment methods for odor control include maintaining aerobic conditions during storage, aerobic treatment (aerated lagoons or composting), anaerobic digestion or biochemical treatment. Oosthoek and Kroodsma (1990) noted a three-fold reduction in ammonia emission rate by flushing the concrete floor in a free stall dairy barn, with minimal ammonia reduction from scraping the concrete floor. Mackie et al. (1998) summarized the work of other authors in reporting that as much as 75% of the nitrogen excreted by feedlot cattle and swine is volatized as ammonia.

For open lot surfaces, rapid drying is the key to odor control. The same should be true for reducing ammonia emissions on a mass basis. Frequent, uniform removal of surface manure and excellent drainage in which manure is regularly harvested leaving a smooth, uniformly sloped pen surface with interfacial layer intact to maintain surface-sealing are also beneficial.
Wet manure on a feedlot or dairy lot surface can be responsible for the generation of significant odor, in terms of both odor concentration and offensiveness. Watts et al. (1994) determined a 60-fold difference in measured odor concentration (in terms of odor units measured with a dynamic forced-choice triangle olfactometer) between dry and wet feedlot surfaces. Odors were highest at mid-day. Odor generation peaked at 2-3 days after rainfall and at a surface moisture content of 60-67% (w.b.). Therefore, feedlots with wet anaerobic manure accumulation will create odor of greater concentration, offensiveness and duration than a well-drained and well-maintained feedlot. Ration had less effect on odor concentration than moisture content.

Well-drained feedlot surfaces with relatively low quantities of manure dry rapidly after rainfall, restoring odor intensities to original levels (Sweeten, 2000a). Feedpen maintenance and manure collection strategies should be aimed at (a) avoiding chronic wet spots caused by poor drainage, potholes, or spills of process generated water; (b) harvesting only the top 1/2 to 2/3 of the feedlot manure; and (c) preserving an uncomposted manure/soil interfacial layer for surface sealing and dentrification. This strategy will help reduce odor, maintain reasonable manure quality as a fertilizer, and protect groundwater.

A feedlot should be designed and managed to shed water. Pen slope of 3 to 5% away from feedbunks or feeding alleys is needed, with discrete drainage provided for each feed pen into a drainage channel that accelerates runoff away from the feedlot surfaces with minimal solids deposition. Potholes should be backfilled as soon as they develop, and overflows or leaks from cattle watering facilities onto the feedlot surface should be avoided. Proper stocking density in pens can ensure that moisture excretion by cattle plus rainfall does not exceed average evaporation in winter as well as summer months.

Several studies have investigated the use of chemical amendments to decrease ammonia emissions from animal manures. Alum additions have been shown to decrease ammonia emissions from poultry litter (Moore et al., 1995) and beef cattle manure (Cole and Parker, 1999). Similarly, urease inhibitors have been shown to decrease ammonia emissions from beef cattle manures in laboratories (Mackie et al., 1998; Varel et al., 1999; Cole and Parker, 1999). Field studies are needed to corroborate these promising trends. The effects of these compounds on emissions of other potentially odorous gases have not been thoroughly studied.

A laboratory study was conducted to evaluate soil amendments for reducing ammonia emissions from open-lot beef cattle feedyards (Shi et al., 1999). A mixture of 1,550 g of soil, 133 g of manure, and 267 g of urine was placed into plastic containers (20 cm X 20 cm X 12 cm depth). Treatments with four replicates consisted of a blank (soil with no manure), control (mixture with no amendment), 4,500 kg/ha $Al_2 (SO_4)_3$ (alum), 9,000 kg/ha alum, 375 kg/ha commercial product (CP), 750 kg/ha CP, 4,500 kg/ha $CaCl_2$, 9,000 kg/ha $CaCl_2$, 9,000 kg/ha brown humates, 9,000 kg/ha black humates, 1 kg/ha of the urease inhibitor N- (n-butyl) thiophosphoric triamide (NBPT), and 2 kg/ha NBPT. Ammonia emissions in air passed over the soil treatments were monitored daily using a hydrochloric acid trap following application of the amendments. Cumulative ammonia emissions after 21 days, expressed as a percentage of the control were: 0.4% for the blank, 8.5% for 4,500 kg/ha alum, 1.7% for 9,000 kg/ha alum, 73.6% for 400 kg/ha CP, 68.2% for 750 kg/ha CP, 28.8% for 4,500 kg/ha $CaCl_2$, 22.5% for 9,000 kg/ha $CaCl_2$, 32.4% for 9,000 kg/ha brown humates, 39.8% for 9,000 kg/ha black humates, 35.9% for 1 kg/ha NBPT, and 34.4% for 2 kg/ha NBPT. Results of these experiments suggest that ammonia emissions from open feedlots can be reduced using chemical additives. However, preliminary cost estimates ranged from less than $1 to more than $33 per head of cattle fed, depending on the product, application rate, and frequency of treatment (Ishmael, 2000). The amount and frequency of treatments, cost-effectiveness, and environmental impacts from the chemical amendments have not been adequately evaluated, and practical use in a commercial feedyard setting have not been demonstrated.

U.S. swine operators have adopted one of two predominant manure management strategies (Miner, 1995): (a) slurry storage under the slotted feeding floor or outside storage tank, with minimal dilution water; and (b) anaerobic lagoon, usually with ample dilution water for hydraulic transport of manure solids. Slurry storage units are more compact, have smaller surface area, and are more amenable to temporary or permanent covers to capture and/or treat odorous gases. These systems tend to be favored in northern states such as the upper Midwest and Northern Great Plains or where terrain or geology does not favor construction of an earthen lagoon. Due partly to concerns with the effects of gases emitted from under floor storage pits and their effects on animal health and performance, there has been a major trend for at least two decades toward frequent removal from building by mechanical scrapers or flushing systems. Many products have been marketed as digestive acids in pits or lagoons, with odor control or odorant reduction touted as a benefit. The National Pork Producers Council has established Purdue University as a laboratory for performing standard tests of these products. For instance, Ni et al. (1999b) found a 24% lower NH_3 emission per hog from spraying underfloor liquid manure storage pits with one such product.

Lagoon systems are usually accompanied by flushing for manure removal from the buildings generally with recirculated lagoon effluent. It is important to observe the distinction between a lagoon and a manure storage, as defined by ASAE (1999c):

> *Lagoon:* An earthen facility for the biological treatment of wastewater. It can be aerobic, artificially aerated, anaerobic or facultative depending on the loading rate, design, and type of organisms present.
>
> *Manure Storage:* A storage facility to contain manure for some period of time prior to its ultimate utilization or disposal. Usually classified by type and form of manure stored and/or construction of the storage, e.g., above or below ground liquid manure tank, earthen storage basin, solid manure storage.

Lagoon systems have tended to be adopted in the southern states and the southern portions of the Midwest and Great Plains where reasonably warm water temperatures most of the year promote treatment (biodegradation). Proper lagoon design and management principles (ASAE, 1999b) are intended to lessen odor intensities as well as achieve operational efficiencies. This includes designing and operating the system for a low volatile solids loading rate. In addition to a properly sized primary anaerobic lagoon, a lightly loaded second-stage lagoon is generally recommended to provide further treatment, effluent storage, and effluent with low odor potential for flushing and irrigation. In cold climates, thermal stratification is pronounced, and spring warming trends leading to inversions (destratification) tends to greatly increase odor emissions for several weeks (Miner, 1995). Moreover, large operations necessitate larger lagoons, with concomitant increases in odor-emitting surface area and thence greater separation distance between the lagoon and neighbors to avoid an odor problem.

Lagoons for livestock manure and wastewater treatment are believed to be a necessity until such time as superior and cost effective technology is widely available (Sweeten, 2000c). These structures have served the public well in terms of keeping enormous amounts of manure and wastewater out of streams, and will continue to do so for another generation at least. However they are a somewhat limited technology. Problems with lagoons that do need to be addressed have generally stemmed from human errors in terms of over-optimism as to design, performance, ease of maintenance, perceived flexibility, and public tolerance for off site impacts. More specifically, these problems can/have included: (a) designing just to meet minimum state regulations for controlling direct discharges into streams; (b) under-design; (c) excessive organic loading, (d) inadequate sealing, (e) increased herd size or liveweight with inadequate compensation for design and management; (f) usage at inappropriate sites/locations; (g) frequent attempts to accomplish both treatment and storage with one single stage lagoon vs. realizing benefits of multi-stage lagoons; (h) insufficient sludge clean out interval or plan for sludge removal/ utilization relative to life of the animal feeding system; (i) regional differences in climate or geology that favor lagoons in certain locations and not in others; (k) emissions ammonia volatilization, and (k) odor, where the above are not adequately observed.

Cheng et al. (1999) observed sequential decreases in odor from raw flushed swine wastewater, covered primary lagoon effluent, and second stage lagoon effluent in terms of odor intensity and irritation intensity. In essence, on an 8-point rating scale, odor intensity was reduced from 6.75 (very strong) from wastewater, to 5.1 (moderately strong) in primary lagoon effluent, to 1.6 (weak) in second stage lagoon effluent. Comparable values for irritation intensity were 5.9 (strong), 3.75 (moderate), and 0.6 (very weak), respectively.

Lim et al. (2000) used a buoyant convective flux chamber to sample odor from two anaerobic lagoons in Illinois and Indiana. Odor concentrations, expressed as odor detection threshold or odor units (OU/m^3), were determined with a dynamic triangle forced-choice olfactometer (DTFCO). Other parameters measured were H_2S, NH_3, and CO_2. Odor concentrations averaged 82 and 144 OU/m^3 for flux chamber inlet and outlet samples, respectively, and average odor emission rate for both lagoons was 3.4 ± 2.6 OU/m^2/sec. Average emission rates for NH_3, H_2S and CO_2 were 98,000 Φg/m^2/sec, 6.1 Φg/m^2/sec, and 1.0 Φg/m^2/sec, respectively.

Heber and Ni (1999) determined that mechanical aeration with static tubes installed in an overloaded anaerobic swine lagoon was very effective in reducing odor emissions. Floating flux chambers were used to capture lagoon surface air samples, which were analyzed by an odor laboratory with a dynamic triangle forced-choice olfactometer at Purdue University. Odor concentrations measured as dilutions to threshold or odor units (OU) ranged from 89-123 OU/min/m^2, and averaged 10 OU/min/m^2 of lagoon surface area, which indicated a total odor emission of 16,200 OU/second. These odor levels were 82% less than the 589 OU/min/m^2 odor emissions measured at two nearby unaerated anaerobic lagoons receiving half the volatile solids loading rate. Total farm odor emission was reduced by 70% with aeration.

4. Capture and Treatment of Odorous Gases

This approach includes the use of covered storage pits or lagoons; soil incorporation of applied liquid or solid manure; and dry scrubbers for building exhaust gases, including soil absorption beds, bio-filter fields, or packed beds. Soil injection or disking manure into the soil after application reduced odor concentrations by 90 to 99% as compared to surface spreading (Lindvall et al., 1974). Kelly (1995) listed 10 technologies for controlling odor from mechanically ventilated confinement buildings (cattle, swine, or poultry) or composting facilities. Hoff et al. (1997) have found that a significant component of swine building odor is caused by odorous compounds that are bound to dust particles, so particulate control methods are applicable as well to odor control.

Soils and organic materials such as peat or wood chips readily absorb odorous gases and provide for aerobic decomposition of captured odorants. Biofiltration has been used for more than 2 decades for odor reduction in composting, rendering plants, solid waste processing and industrial sources (Classen et al., 2000). Sweeten et al. (1991) found that ammonia concentrations in exhaust air at 65-192 ppm NH_3 from a poultry manure composting operation were reduced by 97-99% in air at 76 mm above a 230-250 mm deep fine gravel/sand biofilter field. The biofilter was used to treat exhaust gases captured from the in-bin composting building during the first week of composting. Classen et al. (2000) demonstrated that a biofilter medium of yard waste compost and wood chips (3:1 ratio by volume) at a depth of 50 cm and 15 second residence time reduced odor from pit-stored liquid swine manure. An odor panel evaluation revealed that the biofilters reduced odor intensity (60%), irritation intensity (58%), and unpleasantness (84%).

Safley and Westerman (1990) demonstrated the use of a floating flexible membrane cover to capture and collect biogas (including odorants) produced from a primary treatment lagoon for a 150 cow free-stall dairy to fuel an internal combustion engine and electric generator. Two types of lagoon covers have been proposed: impervious (rubberized or plastic materials) and floating permeable covers (fabric, crop residues, leka rock, etc.) (Miner, 1995).

Van Zeeland et al. (1999) has determined that the most effective means of reducing ammonia emissions from swine confinement buildings is to reduce the surface area of the emitting surface of manure. Proposals to expand the feeding area per head for swine may run counter to the goal of reducing ammonia emissions. The defecating area of weaned piglets in large groups is less than for smaller groups of piglets. This has a positive effect on pen fouling and reduces ammonia emissions.

Verdoes and Zonderland (1999) investigated a chemical scrubber as a means of reducing ammonia emissions from swine growing/finishing houses. The average ammonia concentration in the exhaust air was 10.87 mg/m^3 before treatment and 0.13 mg/m^3 after scrubber treatment

(98.7% reduction, with a range of reductions varying from 90.4-99.9%). Reduced ammonia concentrations through the wet scrubber were measured 91 out of 100 days of observation.

Clanton et al. (1999a) found that six types of manure covers -- straw mat, vegetable oil mat, straw/oil mat, clay ball mat, PVC/rubber membrane, and geotextile membrane -- all temporarily reduced measured odor units (dynamic triangle forced-choice olfactometer) and hydrogen sulfide concentrations in flux hoods over simulated liquid swine manure storage tanks. Effectiveness varied between treatments, and within treatments, with time after manure addition and study initiation. Operating problems included the tendency of straw mats to sink and the vegetable oil to generate secondary odor. The straw mat with vegetable oil and the PVC/rubber membrane cover appeared to be most effective for reducing both odor and H_2S. There was not a statistically significant advantage to covers 48 hours after manure additions.

Laboratory and pilot plant experiments by Xue et al. (1999) determined that two thicknesses (5 cm and 10 cm) of wheat straw applied over anaerobic liquid dairy manure were effective in reducing emission rates of ammonia by 60-95% and of hydrogen sulfide by up to 95% over a 7 week period. The wheat straw cover formed a physical absorption barrier, and also provided a carbon source for improved equilibrium digestion conditions of the surface manure. The process requires further testing for long periods on field facilities.

Heber and Heyne (1999) reported that property line concentrations of H_2S, based on continuous monitoring at a 14,600-head grow/finish swine operation, were twice as high at night as during the daytime. Modest reduction in H_2S emission resulted from addition of a bacterial product to a primary lagoon; greater than 50% reduction in property line H_2S concentration (to 4-10 ppb) resulted from ensuing partial aeration for 41 days (after an initial increase the first week of aeration); and placement of a geotextile/straw cover reduced H_2S concentration further to 0.2-2.8 ppb. The average H_2S concentration with the cover (5 weeks) was only 13% of the mean concentrations before the cover was installed (previous 19 weeks).

Xue and Chen (1999) sprayed 0.5% solutions of chemical oxidants -- hydrogen peroxide or potassium permanganate -- on the surface of anaerobically stored liquid dairy manure flushed from concrete surfaces in a dairy facility. Chemical treatments were applied to laboratory flasks at a depth of 0.2 cm (0.082 inches) at weekly intervals for 5-6 weeks. Ammonia concentrations in the top one-inch (0.25 cm) were reduced by about one half and ammonia emission rates were reduced by 70% compared to the control treatment, due to lower pH as well as surface NH_3 concentration. The potassium permanganate spray treatment reduced ammonia emissions for 4 weeks but they returned to the control levels by the end of the test. Both chemical oxidants reduced hydrogen sulfide concentrations in the top one-inch depth of liquid by 80% or more over 5 weeks, and H_2S emission rates were also lower. The hydrogen peroxide treatment was highly effective in reacting with manure and reducing odorous gas emissions and is recommended over potassium permanganate due to lower cost, better performance, and absence of residue. Mass transfer coefficients for ammonia were one order of magnitude higher than for hydrogen sulfide, but were not affected significantly affected by surface chemical oxidation.

Non-thermal plasma reactors have been used to remove several types of air contaminants such as VOC’s, hydrogen sulfide, and ammonia. Electrical discharge can be implemented in several ways, depending on the configuration (Zhang et al., 1996). Goodrich et al. (1999) devised a laboratory scale dielectric barrier discharge plasma system that removed 100% of the H_2S and 87% of the SO_2 from a synthetic gas stream with three kinds of dielectric materials.

Covered anaerobic lagoons, serving as a psychrophilic anaerobic digesters, are capable of capturing 0.25-0.6 m^3 methane per kg volatile solids loading rate (Cheng et al., 1999).

5. Enhanced Dispersion of Odor

Odor and other air contaminants are diluted to below threshold levels by atmospheric turbulence, which increases with wind velocity, solar radiation, and roughness elements such as buildings, trees or barriers (Miner, 1995). Traditionally, extensive livestock production systems dispersed the odor by having thousands of small farms scattered over the terrain, so that no one farm generated sufficient odor to be a major community problem. The most intense odor occurs under nightly stable atmospheric conditions, known as inversions. Means of technologically dispersing the aggregate of the odor from the larger production units may be needed in site-specific cases.

Sound site selection for CAFOs with adequate separation distance and, if necessary, elevated sources or mechanical turbulence will help achieve odor dispersion and avoid nuisance conditions. Odorants may be transformed between the source and the receptor, and this includes interactions with other odorous gases or particulates (Peters and Blackwood, 1977). Ammonia and hydrogen sulfide are highly reactive, have relatively high odor thresholds and low molecular weights and disperse rapidly (i.e., low persistence factor) (Summer, 1971).

Sound site selection is the simplest and cheapest odor control strategy (Kelly, 1995) that protects investments in new concentrated animal feeding operations and surrounding real estate and avoids exorbitant expense of legal actions involving odor nuisance. To achieve good dispersion, operators should choose a remote site relative to neighbors; gently sloped topography without confining valley walls; and low probability of wind direction toward nearby neighbors, coupled with stable atmospheric conditions that retard dispersion.

Land application is a frequent cause of odor complaints and can be minimized or eliminated by daily site selection with regard to distance and wind direction frequency considerations and by use of adequate treatment systems (as above) to produce a well-stabilized wastewater or compost (Miner, 1995). Irrigation systems that produce low visibility or spray drift (e.g., level borders, low pressure sprinklers, or spray nozzles) will be less likely to trigger odor complaints.

Most dispersion models are based on the Gaussian plume dispersion equation, which is convenient but not very reliable where topographic features are involved (Miner, 1995). Development and use of emerging technology for modeling of odor dispersion requires knowledge of emission rates (i.e., concentration times airflow rate) as a surrogate for mass emission rate (Smith and Watts, 1994a; McFarland, 1995). For instance, Smith and Watts (1994a) used dynamic forced-choice triangle olfactometer measurement to calculate odor emission rates ranging from 5 OUm/s for a dry feedlot pad to over 500 OUm/s for a wet feedlot pad, and these data were used to model dispersion. Modeling will be used in the future to predict odor impacts on surrounding land users more accurately in advance, before projects (agricultural or non-agricultural) are actually built. However, much more research is needed before accurate odor models are developed, calibrated, and utilized with accuracy. The non-linear/non-additive nature of odor emissions from contributing sources makes it difficult to predict odor emission rates from complex sources, such as feedlots and dairies (Kelly, 1995).

Miner (1975a) observed that odor concentrations as determined with the Scentometer and ammonia concentrations diminished rapidly with distance downwind of a cattle feedlot. Effective measurements of ammonia concentrations were possible only up to 200 m downwind from the feedlot, because of the low levels of ammonia evolved at the source and dilution from the wind. Ammonia concentrations were reduced by 82 to 96% within 120 m (400 feet) from the corrals.

One means of insuring substantial buffer distance between a confinement swine operation and off-site residences is to balance the amount of land with nutrient needs of crops or forages (Sweeten, 1998). In many cases, this land area, determined perhaps through a CNMP, may be large enough to ensure an adequate buffer distance for odor control. There is often a tendency to underestimate land area requirements through the use of optimistic or unrealistic estimates of nutrient “losses” (e.g., high rates of ammonia volatilization, sediment in lagoons, etc.) or nutrient recovery by crops. Where nutrients are not properly accounted for, both water and air quality are at greater risk, along with lessened opportunities for economical nutrient recovery. Design aids and management tools are available to guide the producer toward providing and maintaining adequate land area for manure and wastewater application. Standard values for manure and nutrient production are provided in ASAE standard values (ASAE, 1997) based on animal liveweight. These values are used in various spreadsheets that can be used to estimate total nitrogen and phosphorus production, size of treatment or storage facilities, approximate nutrient losses and nutrient uptake by crops (Baird, 1993; Schulte et al., 1994; Sweeten et al., 1993).

Sweeten (1998) developed examples of determining phosphorus and nitrogen balances, the resulting theoretical minimum separation distances, results of field odor concentration measurements at two swine operations, and required distances to reach near-background odor levels. He determined that for swine confinement facilities, larger acreages will be needed to provide a phosphorus balance than for an N balance, which may be an advantage for odor control. Odor diminished generally with distance downwind and for both farms, odor concentration (dilutions to threshold, DT) was found to be related to downwind distance (χ, feet) through logarithmic relationships.

An odor concentration of 2 DT was found to be consistent with background odor levels (Sweeten, 1998). It is regarded as a low odor strength and a level that does not cause odor nuisance conditions (Barnebey-Cheney, 1987), and is also a level that has been used as a property line standard in several jurisdictions (Sweeten, 1990). Accordingly, the odor vs. distance regression relationships indicated that a distance of 790 m (2,600 ft) from the odor source resulted in 2 DT at the 200-sow farm using a scrape, storage pit, soil injection system. A greater distance -- 2,300 m (7,580 ft) -- was required for the larger operation (8,400 sow operation) to achieve 2 DT, using a flush/lagoon/sprinkler irrigation system. From the data presented, for both Systems A and B, distances required for odor control may exceed the minimum indicated for N balance, but less than needed for P balance considering complete P recovery from lagoons or other treatment/storage limits over the life of the systems.

It is important that the site selection and design be based on information that will result in adequate separation distance with respect to odor nuisance protection and also site sustainability from the standpoint of protection of soil and water quality (Sweeten, 1998). These objectives can be met by selecting the greater of the two distances -- odor reduction vs. nutrient management objectives. Alternatives to providing the necessary distances might be to redesign the manure and wastewater management system to reduce odor concentration at the source or improve opportunity for odor dispersion. Otherwise, choosing an alternative location or downsizing the operation should be considered.

6. Summary of Odor Control Opportunities

Odor control is of increasing concern and in the immediate future, application of those technologies available will be required to a greater extent (Miner, 1995). Aerobic systems and enclosed anaerobic storage/treatment of manure have obvious application. The use of enclosed manure storages and direct soil injection is possible in many more locations than is now practiced. Of paramount importance to the success of present day systems is to avoid overly optimistic assumptions in assessing manure production and treatment efficiencies in the design of storage, treatment, and land disposal systems. Overly optimistic design assumptions in these areas have frequently been utilized to justify placing an operation on a particular parcel of land that is too small. These short term expediencies result in operations that are more likely to lead to odor conflicts or environmentally unsustainable systems from a nutrient management perspective. Cost saving measures in site selection and facility design can lead to higher cost, including expensive retrofits and neighborhood conflicts in later years.

CANDIDATE DUST (PM) CONTROL PRACTICES

Feedlot dust is generated by cattle activity, which has peak activity in early evening hours. MacVean et al. (1986) linked the health and performance of feedlot cattle to episodes of feedlot dust. Table 7 provides a matrix of particulate matter control approaches for either confinement buildings or open lot feeding systems, as well as solid manure storage and land application (Auvermann, 2000). The primary predictor of dust and odor emissions is the manure moisture content. There are conceptual tradeoffs between feedlot odor and dust. An optimum moisture content appears to be between 25-40% wet basis (Sweeten et al., 1988).

Feedlot dust control approaches include: stocking density adjustment (taking advantage of manure moisture excretion); frequent manure collection; and water application via mobile equipment or sprinkler irrigation. Water requirements for dust control can approach cattle drinking water requirements in dry seasons; a typical guideline is 2.5-6.0 mm/day (0.1-0.25 in/day). Future research will incorporate on-site climatic monitoring and surface drying models for application of dust control measures. Romanillos and Auvermann (1999) conducted 16 feedlot PM sampling events at a 60,000 head commercial feedlot in the Texas Panhandle to determine whether stocking density at 13.9 m^2/hd vs. 7.0 m^2/hd, with associated increases in excreted moisture per unit area, affected dust concentrations. After 8 months of test results, the higher stocking density (i.e., reduced spacing) resulted in measurable reductions in PM concentrations, although data analysis is still being conducted.

Original USEPA estimates of so called “emission factors” for feedlot dust were excessive (based on dry season southern California conditions), and improved emission factors are being developed to include recent research at Southern Great Plains feedyards.

CURRENT RESEARCH PROGRAMS TO ADDRESS PROBLEMS

1. General Characterization of Prior Research

There is a considerable amount of research supported by a diverse group of private, state, and/or federal agencies addressing air quality and confined animal feeding operations and its effect on human health. Biological Abstracts from 1985 to the present of air quality studies listed 1,240 entries from around the world. Narrowing the search to air quality and animals yielded 426 entries of which the vast majority dealt with human health-related issues. However, a study by Clausnitzer and Singer (1996) attempted to quantify respirable-dust production from agricultural operations in the Sacramento Valley of California. They reported that the highest average of respirable-dust concentration was 10.3 mg/m^3 air from soil ripping and land planting carried out on dry surface soil. The lowest dust concentration was from disking of corn stubble (0.3 mg/m^3) into soil during the wet season. Approximately 64% of all operations were performed during hot and dry weather producing 83% of the annual respirable dust for the three-crop systems.

In an effort to identify whether other studies were being conducted to quantify particulate matter from animal feeding operations, the USDA Current Research Information System (CRIS) database was searched for studies dealing with animal feeding operations. Several studies were found addressing air quality from its effects on human and animal health and the development of technology to control the dust and odors emitted from the facilities. However, there were only a few studies trying to quantify and predict the amount of particulate matter and offensive odors generated by these confined animal operations. For example, it has been shown that electrostatic air cleaning technology (EAC) can improve indoor air quality (IAQ) by reducing the indoor particular load for very fine particles caused by outdoor air pollution by 78%. It can also reduce the number of fine particles produced indoors by 45% according to Rosen and Richardson (1999), who stated that EAC technology is cost effective and might be a way forward to improve IAQ. This type of technology may prove useful in areas that are affected by agricultural burning operations.

Terpenic compounds have been reported to be effective in reducing the air bacterial contamination in livestock buildings. A new terpenoid called vyterol decreased air bacterial contamination by 64.6 - 71.6% and body resistance improved which ensure a two-fold decrease in the rate of calves respiratory disease and 11% increase in average daily weight gain (Frolov, 1997). Canola oil has been shown to be effective in controlling dust and thereby improving indoor air quality in swine barns according to Senthilselvan et al. (1997).

It is clear that more research is needed to quantify the contributions of all agricultural operations to the air quality issues we are facing. The research areas proposed by this Task Force is a start that could help the agricultural industry and regulators assess causes, importance, and corrective measures of air pollution control.

2. Health Issues/Risks

Most of the human health related research on confined swine production facilities has focused on the health of workers working inside the facilities (Thorne et al., 1996; Thu, 1996). Since the late 1970s, over 25 published studies worldwide have consistently documented a number of occupational health problems among swine confinement workers. The most notable of these are a series of interrelated respiratory conditions such as chronic bronchitis and organic dust toxic syndrome that occur in approximately 25-30% of swine confinement workers (ibid:164). Recommended gas (7 ppm ammonia), dust (2.5 mg/m^3 total dust; 0.23 mg/m^3 respirable dust), and endotoxin (100 EU/m^3) levels have been developed for interior swine confinement operations based on dose-response research among confinement workers in relation to environmental conditions (Donham et al., 1995; Reynolds et al., 1996).

Most research over the last thirty years on the external environment surrounding large-scale livestock operations has focused on identifying compounds producing odors (Mackie, 1995; Miner, 1975b; O'Neill and Phillips, 1992), mechanisms for measuring odor (Barrington, 1995; Hobbs, 1995), and the development of control technologies (Lwo, 1995). Much of this work primarily examines odor as a nuisance issue that should be addressed because it can interfere with the quality of lives of neighbors. However, a notable shift has occurred in the last few years as rural physicians receive an increasing number of health complaints from neighbors of large-scale swine operations. Emerging research and results from several recent scientific conferences provide evidence of a paradigm shift from one that views odors as a nuisance to one of assessing odors and associated emissions as a public health issue.

Four studies have been conducted directly assessing the health of neighbors living in the vicinity of large-scale swine operations, three of which have been published in the scientific literature (Keller and Ball, 2000; Schiffman et al., 1995; Thu, et al., 1997; Wing and Wolf, 1999). In 1995, Schiffman et al. (1995) at Duke University published the results of a matched control study examining the psychological effect of odors from commercial swine operations in North Carolina. They administered a standardized mood states (POMS) and total mood disturbances (TMD) scale to 44 neighbors of commercial swine operations and 44 matched controls not living near such operations. Results showed that the neighbors subjected to odors scored significantly higher on the POMS/TMD scale, exhibiting significantly higher rates of tension, depression, anger, and fatigue than did the control group. Elsewhere, Schiffman et al. (1998) described a variety of mechanisms that explain how odor can have a deleterious human health effect, including a physiological pathway between the olfactory lobe and the immune system, which directly implicate odor as a health risk.

Researchers at the University of Iowa published the results of a comparative control study built on the earlier work of Schiffman (Thu et al., 1997). They collected data on the physical and psychological health of neighbors living within a two-mile radius of a 4,000 sow swine confinement production facility and compared the results with data from demographically comparable rural residents who lived near minimal livestock in Iowa. Results indicated that the neighbors of the swine operation reported significantly higher rates of four clusters of symptoms that have previously been documented to represent toxic or inflammatory effects of the respiratory tract. Most notable is the fact that the configuration of respiratory symptoms fit a well-documented pattern of respiratory health problems among swine confinement workers. However, no differences between the two groups in psychological health were apparent as reflected in the standardized anxiety and depression scales that were administered. It should be noted that this finding does not contradict Schiffman's earlier work since the scales employed by Thu et al. (1997) measured different dimensions of mental health.

In 2000, two independent and separate epidemiological studies commissioned by the state health departments in North Carolina and Utah respectively examined the health of swine CAFO neighbors (Keller and Ball, 2000; Wing and Wolf, 1999). In North Carolina, Wing and Wolf (1999) used a comparative control methodology to assess health symptom reports among neighbors of swine CAFOs compared with neighbors of cattle operations and matched rural controls not living near any livestock operations. The results indicated a significantly higher rate of reported respiratory symptoms among swine CAFO neighbors consistent with the findings of Thu et al. (1997). In Utah, Keller and Ball (2000) examined diarrheal and respiratory illness incidence rates among residents living near Milford, Utah near one of the largest swine CAFOs. Based on hospital discharge data collected between 1992 and 1998 (the period in which the CAFO was constructed and became operational) residences of Milford experienced a significantly higher incidence of respiratory illness compared with control populations. The findings are consistent with the earlier work.

One of the suspected culprits in creating neighbor health problems is hydrogen sulfide. Chronic or acute occupational exposure to hydrogen sulfide concentrations near or above 500 ppm (parts per million) is known to result in Acute Respiratory Distress Syndrome (ARDS) or pulmonary edema among swine confinement workers (Thorne et al., 1996). Approximately 20 deaths in swine confinement workers have been reported from exposure to hydrogen sulfide. High level exposures usually occur from agitation of liquid manure in a confined space, where this type of manure handling system is in place. In 1987, the World Health Organization recommended a maximum 107 ppb (parts per billion) ambient air level over a 24-hour period to prevent health problems and 5 ppb over 30 minutes as a threshold for odor nuisance (Sheldon, 1993). These levels compare to OSHA occupational exposure limits of 10,000 ppb for an 8-hour workday (time weighted average). The Minnesota Pollution Control Agency (MPCA) collected data on hydrogen sulfide levels near ten livestock operations in that state and five of the operations exceeded the state standard of 30 ppb (Ison, 1998). Minnesota appears to be one of the few states which actively measure gas levels and applies the WHO standard. Other states have different standards.

It is as yet unclear to what extent hydrogen sulfide, acting alone or more likely in combination with one of the other 160 compounds generated from swine waste, contributes to neighbor health problems. Perhaps most notable in this regard is the fact that research indicates little relationship between hydrogen sulfide and odor levels (Jacobson et al., 1997). This raises the concern that if there is indeed a health problem from livestock emissions, we may be mistakenly assuming that taking care of the odor issue is synonymous with addressing the public health problem. Research is clearly needed to assess the dose-response relationship between neighbor health conditions and swine CAFO emissions.

3. Current Research Levels

The U.S. Department of Agriculture's Agricultural Research Service (USDA-ARS) and Cooperative State Research, Education, and Extension Service (USDA-CSREES) are the principal federal agencies conducting or supporting research to develop new or innovative animal waste management practices. In recent years these agencies have conducted or sponsored research to reduce and stabilize the nutrients in animal wastes and to improve waste composting techniques. The GAO (1999) reported that for fiscal years 1996 through 1998, the USDA-ARS spent $13.5 million for this type of research; it expects to spend an additional $9.1 million in fiscal year 1999 having grown from just $3 million in 1996. The USDA-CSREES spent $6.9 million for this type of research in fiscal year 1997; data for fiscal years 1996 and 1998, as well as an estimate for fiscal year 1999, were not available. The CRIS (Current Research Information System) database identified nearly 400 research projects in FY 1997 that related at least in part to animal waste management, including odor.

RESEARCH NEEDS ASSESSMENT

1.   PM Emission Factors

The air pollution regulatory process is designed to protect the public. One goal of the process is to insure that the public is not exposed to pollutant concentrations that are unhealthy (Parnell and Wakelyn, 1996 and 1999). If it is perceived that an ambient concentration is too high, then the allowable emission rates of all permitted sources of the pollutant are reduced by rule (Parnell, 1992). Emission factors are used to estimate emission rates and are an integral part of the permitting process that establishes the allowable emission rates of permitted operations. In addition, emission factors are used to estimate downwind concentrations of the pollutant that potentially could impact the public. Buch et al. (1998 and 1999) discussed the accuracy of PM_{10} and $PM2_{2.5}$ measurements.

There is a need for accurate emission factors that depict the mass of regulated pollutant per unit of operation of the agricultural process. For example, the AP-42 emission factor for a cotton gin is 3.05 pounds of total suspended particulate matter (TSP) per bale of cotton ginned. In Texas, this emission factor is assumed to be associated with an air pollution abatement system described by 1D3D or 2D2D cyclones on all centrifugal fan exhausts and covered condenser drums on all axial-flow fan exhausts. This abatement system is referred to as Baseline Best Available Control Technology (BBACT). A 20 bale–per-hour (bph) cotton gin with BBACT will be projected to emit 61 pounds of TSP per hour. However, the regulated pollutant is not TSP but PM_{10}. It is generally accepted by air pollution regulatory agencies (EPA and SAPRA) that the PM_{10}/TSP fraction of particulate matter emitted by a cotton gin is 50%. Hence, the emission rate of PM_{10} a cotton gin (with BBACT) is 30.5 pounds per hour. If the gin operates for 1000 hours, the annual emissions inventory would be 15 tons of PM_{10}. An alternative calculation of emissions inventory would be to use the emission factor for PM_{10} (1.5 lbs/ton) times the number of bales ginned per year. If the gin processed 25,000 bales per season, the annual emissions inventory would be 18.75 tons of PM_{10} per year. What if the cotton gin had a more efficient abatement system, what would be the emission rate and annual emissions inventory? Is the emission rate accurate?

A cotton gin will typically have 10 process streams. The characteristics of the particulate matter emitted by each of the process streams can vary. In reality, some of the process streams will have a PM_{10}/TSP fraction significantly less than 50%.

EPA has published a number of emission factors for agricultural operations in AP-42 (EPA, 1995) but a number of these emission factors are incorrect. One of the best examples of an incorrect emission factor is the AP-42 emission factor for grain elevators and feed mills (Shaw and Parnell, 1997; Shaw et al., 1998; Demny et al., 1997; Buharivala, 1998) {These incorrect emission factors were recently corrected by EPA.} The 1988 AP-42 emission factor was 8.6 pounds of TSP per ton (lbs/t) of grain processed in a country elevator and 9.8 lbs/t (TSP) for a feed mill. These emission factors were based on study results reported by an EPA contractor with no Agricultural Engineering expertise and mistakes were made in the protocol. Based upon more recent study results, the PM_{10} emission factors for both country elevators and feed mills have been changed to less than 0.5 lbs/t.

There are a number of agricultural operations that do not have emission factors or the emission factors are based upon poor science. Some examples included, field operations; ammonia and H_2S from CAFO lagoons; odors from cattle, dairy, and poultry operations; and PM_{10} and $PM_{2.5}$ from agricultural burning. When State Air Pollution Regulatory Agencies (SAPRA) have problems with agricultural sources, the industries are at the mercy of the SAPRA staff. Any number can be used without consideration for sound science and engineering. The cost of correcting an erroneous emission factor or generating a new one is approximately $100,000.

2. Odors and Odorants

The USDA Agricultural Air Quality Task Force (AAQTF, 1998) has developed a recommended research program on odors (Table 8). While some work is in progress related to the AAQTF proposed research agenda, much remains to be completed. The current level of research activity is far below that proposed by the AAQTF. Creative solutions to the odor issue may be needed to forestall more drastic public measures such as stringent siting standards or zoning limitations on livestock facility siting at the state and local and national levels.

More attention may need to be given to means of handling slurries, so that they can be soil injected. Although this is not possible part of the year, and maybe not practical on some soils and/or into some cropping practices, if the cost of odor control continues to increase, we might find that the best overall economics exists by not cropping part of the land associated with a livestock operation, just to preserve the ability to soil inject livestock waste material, at least during the warmer parts of the year when the odor problems tend to be worse.

Likewise, a study is needed to determine costs vs. benefits with respect to CAFOs and near-by residences. Community support for investments in odor control measures on the livestock operation, so as to reduce the odors to more acceptable levels, without losing the jobs associated with the livestock operation to other nations is a potential area of further research.

Wing and Wolf (1999) reported to the North Carolina Dept. of Health and Human Services that odor is one of the issues which affects the quality of life of those who live near confined animal feeding operations (CAFOs). Odorous compounds provide citizens with evidence that chemical contaminants are present in the atmosphere. The residents reported health effects that indicate that chemical compounds and biological particulate matter associated with the CAFOs affected their health. There is a need to understand the impact of separation distance on quality of life and human health. More research is needed to characterize air quality as a function of distance from large CAFOs. Odorous compounds such as ammonia can be measured as a function of distance and the results can be correlated with other contaminants such as microbial numbers or endotoxin. Sweeten (1998) addressed separation distances based on odor and waste management. These two studies provide a starting point for more research. The issue of safe separation distance is growing in importance, and it should be included as part of the research on odors and dispersion. It may be possible to reduce the required separation distance through better odor control technology.

Some states are either regulating odors or moving toward regulating odors associated with CAFOs. An example is the Colorado odor emission regulation for large swine operations. One of the policy issues relates to whether specific gaseous compounds (e.g., ammonia, ammonium, organic nitrogen compounds, hydrogen sulfide, etc.) should be regulated in addition to those listed in the Clean Air Act Amendments.

Since odors are produced by many compounds, the research efforts must consider the important individual compounds that cause the odors and the processes to measure, manage and control them. The matrix of odor sources and locations (Table 6) shows that odorous chemicals need to be managed by addressing those processes where the odor is generated. The environment where the animals are confined and the waste treatment facilities are often important sources of odorous compounds. Research to understand the chemical and biological processes that result in emission of odorous compounds is often an important step in developing new processes which reduce odors. This research must include work to measure and characterize the important odorous compounds.

Prior research has established that peak odor conditions may occur at 65% or higher feedlot manure moisture, and dust conditions can be expected at below 25% moisture (Sweeten, 2000a). Reliable evaporative drying relationship are needed to predict the early onset of odor or dust conditions and enable timely interdiction strategies. Correlations between onset of drought conditions in crops and pasturelands, which are being widely studied and modeled, versus dust conditions in feedlots are needed. Odor research has not been systematically conducted with corn-based rations (the staple grain ingredient of the U.S. beef cattle feeding industry) in a feedlot environment, let alone for alternative ration ingredients, ration supplements, and potential odor control products. Long term research with standardized sampling and measurement equipment is needed.

Future research needs to include: reduced ammonia volatilization, reduced or improved availability of P in beef cattle rations and thereby, lower levels of pH in manure; and N/P ratios in manure that approximate crop nutrient uptake rates (e.g., 4:1, 5:1, etc.) as compared to approximately 1:1 or 2:1 today (Sweeten, 2000a). With watershed-based stream water quality standards being increasingly dictated by P limitations, and hence, lower manure application rates, there is no longer an incentive to waste nitrogen to ammonia volatilization, where it can become an air quality liability.

In the past, nutrient budgets have been “balanced” by ammonia losses from the feedlot surface that can run as high as 50% or more. Now, however, with water quality focus shifting to phosphorus rather than nitrogen, application rates will trend lower and indeed N will be needed to approximate the plant N/P utilization ratio on most crops. Moreover, N volatilization is presently seen as a potential precursor to fine particulate $PM_{2.5}$, which is targeted as a future criteria air contaminant. Technology is being developed at the laboratory scale for feed additives or surface treatments that will reduce ammonia emissions for cattle manure (Shi et al., 1999), as has previously been addressed with swine manure.

According to Miner (1995) and others, research opportunities having potential to reduce odor complaints for swine operations and related facilities include:

a. Improved odor identification and measurement --
- Improve electronic detection systems that offer potential to eventually replace labor intensive, high cost methods of olfactometry.
- Better define interactions between odor production, separation distance, climatic data, land uses, and public acceptance.
- Develop appropriate odor indicator compounds (Zhu et al., 1999) such as (long chain) volatile fatty acid compounds or specific microbes.

b. Better building design alternatives --
- Improve manure removal efficiencies from surfaces.
- Reduce manure volume and surface area.
- Develop innovative building exhaust air treatment processes.
- Improve knowledge and application of dynamics through site selection and dispersion acids (trees, barriers, etc.).

c. Manure management system --
- Manure handling systems that conserve rather than volatize nitrogen.
- Energy recovery systems, including biogas production.
- Implement scientifically sound programs of evaluating new products (biochemicals, permeable lagoon covers, etc.).

d. Land Application --
- Develop short term, temporary treatment alternatives for odor reduction prior to land application (e.g., aeration, chemicals, dilution, etc.).

3. Dispersion

With the increasing frequency of interaction between confined animal feeding operations (CAFOs) and the public, there is a need for research to understand both the emission rates of particulate matter, ammonia, and odors, and to model the effects on downwind communities. Basic research is needed to define the emission rates of particles, ammonia, and the chemicals responsible for odors. The emission rates must be established as a function of time of day, season, and atmospheric variables such as temperature and relative humidity.

The emission rates of primary particulate matter have been studied to some degree, but there is insufficient information to establish them as a function of time of day or season. A significant effort is required to complete this work, but the objective is easily attainable. There has been somewhat less research on the emissions of ammonia, but there are no real technical hurdles to overcome in this area. A significant effort is still required, but it will be relatively straightforward to accomplish the objective of understanding the diurnal and seasonal emission rates of ammonia.

There is a need to establish an objective, quantitative method for the measurement of odors. The current methods that rely on panels of observers are only semi-quantitative, at best. Research underway at the University of California-Davis, Iowa State University, and Texas A&M

University is aimed at establishing more objective methods to quantitatively measure odors. This work should be continued in earnest. After establishing a method for measuring odors, further research is needed to understand the mechanisms by which they are emitted into the atmosphere.

There is a need for accurate models to predict the downwind dispersion, transformation, and deposition of particulate matter, ammonia, and odorous gases. The primary emissions of particulate matter can contribute directly to the atmospheric burden of particles. Deposition of larger particles, however, would reduce the impact. Both these processes must be better understood. The role of ammonia in secondary particle formation is fairly well known, but the emission rates and the deposition and dispersion parameters must be better understood. In particular, the emission rates of ammonia during fertilization and subsequent uptake by the crop canopy are not well known. Finally, accurate models are needed to predict the downwind effects of odorous compounds emitted from CAFOs.

Dispersion modeling is used to (1) estimate downwind concentrations and (2) back-calculate emission factors given measurements of downwind concentrations. Emission inventories are used by SAPRA in their strategic planning to reduce exposure of the public of PM_{10}. If the existing emission factor is in error, and is multiplied by a large number, the resulting emissions inventory will be in error. For example, in Texas, there are approximately 3,000,000 head of cattle on feedyards each year. An error of 10 pounds of PM_{10} per 1000 head per day (lb/1000hd/d) would result in an error of over 5,000 tons in the emissions inventory.

The determination of emission factors is not as simple as some would perceive. A measurement PM_{10} concentration does not yield an emission factor, directly. One of the key variables in determining emission rates and emission factors is the dispersion model used to back-calculate the emission rate. Parnell et al. (1993) used the EPA approved Fugitive Dust Model (FDM) and data reported by Sweeten et al. (1988) reported that a more correct PM_{10} emission factor for cattle feedyards would be 2.5 lb/1000hd/d. McGee (1997) used the Industrial Source Complex version 3 (ISC3), and concentration data reported by Sweeten et al. (1988) reported that a more correct emission factor for PM_{10} for cattle feedyards would be 20 lb/1000hd/d. Neither of these authors corrected for rainfall events. Both used the same data and reported different results because they used different dispersion models to back-calculate the emission factor.

The AP-42 PM_{10} emission factor for cattle feedyards is 70 lb/1000hd/d. This 70 lb/1000hd/d factor was reported by Peters and Blackwood (1977) using concentration data reported by Algeo et al. (1972). Peters and Blackwood used a line source algorithm to back-calculate the emission rate but they made significant errors and a number of assumptions that could not be verified. Parnell et al. (1999) used new concentration data with ISC3 and found that a more correct PM_{10} emission factor should be 15 lb/1000hd/d (corrected for rainfall events).

Meister et al. (1999) reported on research progress in the development of a new model that could be used to predict downwind concentrations from ground-level sources that addressed the problem of the Gaussian distribution in the vertical plane. The ISC3 model reflects the portion of the normal distribution in the vertical plane that would theoretically be under-ground resulting in a maximum concentration at ground level. This unique distribution was referred to as a "double-normal" distribution. In reality, the maximum concentration in the plume downwind moves upward as the plume moves away from the source. Meister replaced the “double-normal” distribution with a triangle distribution. Some researchers have used a “box model” to back-calculate emission factors. For example, if the plume height were assumed to be 4 meters with a field width of ‘W’ meters, the box area would be ‘4W’ m^2. Given a wind velocity ‘u’, the volume rate of flow could be determined and with a concentration measurement, one could calculate the mass of PM_{10} emitted.

Emission factors are a measurement of the PM_{10} emission rate from the pollution source or sources. For a cattle feedyard, the source of PM_{10} is the manure pack -- the area where cattle are walking and stirring up dust that can be carried by wind to the sampler. The sampler is stationary throughout the sampling period. Wind direction and velocity cannot be controlled. If the uncontrollable factors result in a measurement of PM_{10} concentration that is not an accurate indicator of PM_{10} from the pollution source, that data should not be used to determine the emission factor. (For example, if the wind direction was such that the dust came from a field off to the side of the feedyard, the concentration measurements could not be used to estimate in an accurate emission factor for cattle feedyard.) Note that the measurement of PM_{10} concentration with the situation depicted in Figure 1a would not be related to the emission rate (factor) of the feedyard surface.

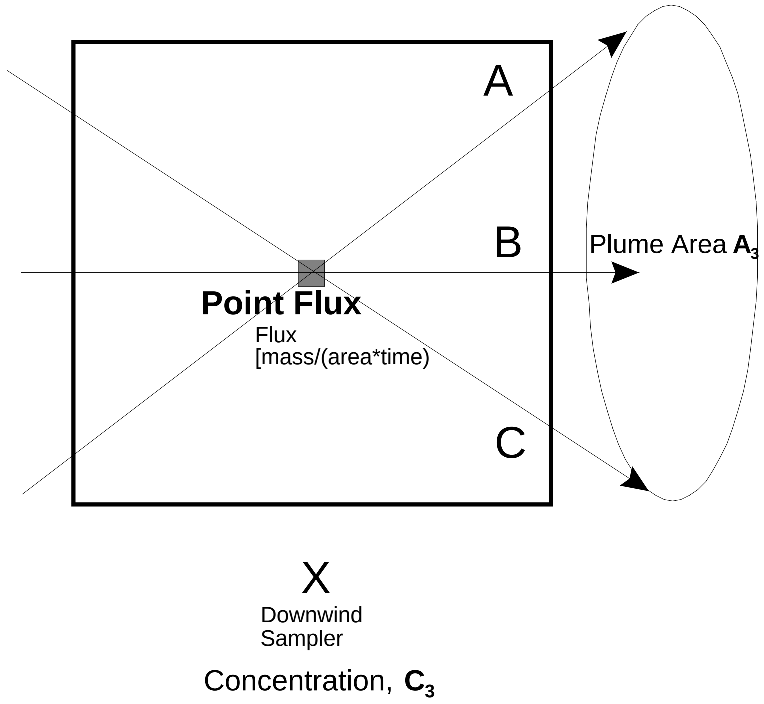

Figure 1a

Another factor that is misunderstood is that emission factors are not directly proportional to concentration. In other words, a high PM_{10} concentration does not necessarily mean that the emission rate is high. (This is counter-intuitive because the public would believe that a high concentration would indicate that there was more dust being emitted from the source.) To illustrate this, refer to Figures 1b and 1c. In this simple example a square feedyard with a constant emission rate (factor) is the source of the PM_{10}. If the change in wind direction for one sampling period is wide (Figure 1b) compared to another sampling period where the change in wind direction is narrow (Figure 1c), two different concentrations will result for the same emission factor. This is a consequence of the same mass of dust being emitted but this mass is dispersed into different volumes. Concentration measurements are a measure of mass per unit volume. All determinations of emission factor (rate) must be calculated using a dispersion model that accounts for changes in wind direction and wind velocity.

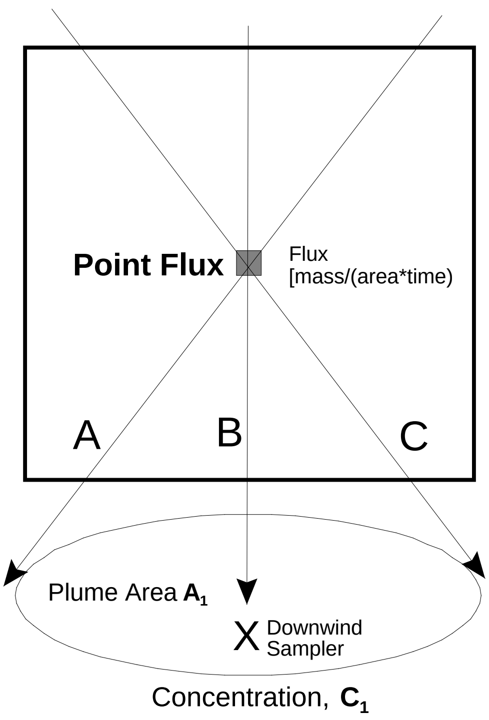

Figure 1b

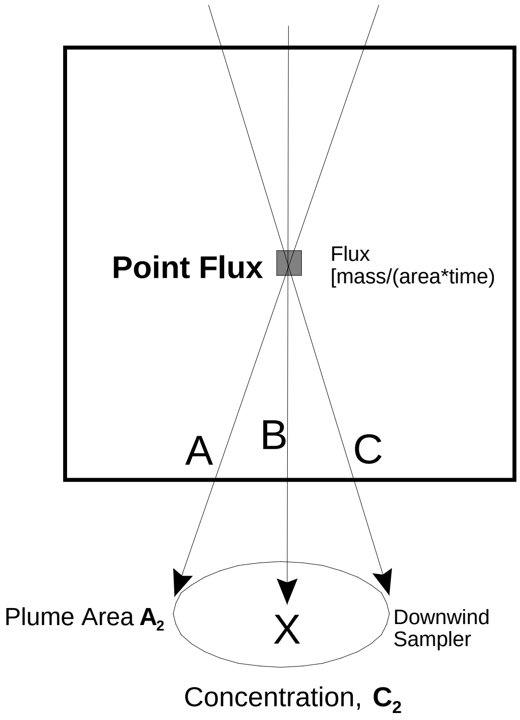

Figure 1c

4. <u>Indoor Air Quality, CAFO Buildings</u>

Indoor air quality is a significant concern in swine and poultry production. Ammonia, hydrogen sulfide and odorous compounds dissolved in the air and particulates are present in indoor air in CAFOs. The particulates include dust from feeding activities and animal movement as well as particles from the animals and feces present in the building. The dissolved gases and particulates impact both animal and human health (Donham et al., 1986; Donham et al., 1989; Hartung, 1994; Thorne et al., 1996). Several studies have been conducted to characterize the dust in confined CAFO facilities (Heber et al., 1988a and 1988b; Maghirang et al., 1995; Maghirang et al., 1997; Maghirang and Puma, 1997; Pickrell et al., 1993; Riskowski et al., 1998). The dust particles often include endotoxins, mycotoxins, bacteria, fungi, virus, insect parts, feces, and proteins, as well as inorganic matter.

Ventilation research to develop better methods to manage and control indoor air quality is in progress at Kansas State University and other locations. Methods to remove particulates from the air are being investigated as well; however, more research is needed to address this important problem of indoor air quality in CAFOs. Finding solutions that are cost effective is a significant challenge.

5. Health Effects

It appears from Wing and Wolf (1999) there may in fact be identifiable health concerns associated with certain confined livestock installations in relation to health and quality of life issues near livestock operations. It suggests there may be further avenues to explore relative to health affects.

Conversely, the data also suggests either no adverse or even positive health benefits from living down-wind from a cattle operation, in that the respondents reported less of certain problems in the cattle areas, than in the control areas. Here again, this might merit further investigation. Experience with animals suggest there are in fact some differences among various categories of livestock in their response to various treatments, and perhaps there may be similar differences among humans, based on gender, race, geography, childhood environment (rural vs. urban), etc., in response to agricultural air quality exposures.

Wing and Wolf (1999) suggested strongly that we cannot ignore the issue of livestock odor, and the associated particulate chemistry, physiology, geology, and transport. It appears that much more needs to be understood about kinds of bacteria, viruses, etc., from confined livestock are being carried on airborne particulates emitted from or passing through the vicinity of livestock operations. The geology, agronomics, and natural vegetative status of the location of livestock operation might need closer attention.

There is a need to conduct research to address the air quality environment in confined swine and poultry CAFOs. Further research is needed to understand the health effects. Because of the large number of different contaminants present, the identification of compounds that impact health is difficult. Very little has been done to relate cause and health effect in the complex swine environment where several contaminants may be acting together to have an effect that is much greater than any of them alone. For example, ammonia adsorbs to dust particles and may be carried to the lungs by small dust particles. Biological particulate matter is of concern and endotoxin has been reported to affect worker health.

Research is needed to characterize the chemical compounds dissolved in the air, the sources, sizes and composition of the dust particles, and the biological particulate matter. The biological particulates are of significant concern. They include non-pathogenic and pathogenic organisms; bacteria, mycobacteria, fungi, and viral components; endotoxins, mycotoxins, glucans, and other microbial products; aeroallergens; insects and insect parts. Swine influenza can be transmitted to humans. Hepatitis E can be transmitted from swine to humans. Thus, research is needed to more fully characterize the air, especially the particulate matter.

Technologies that can be used to reduce and control the level of contaminants in the air are needed. While some research has been completed on dust reduction with oil sprays and ventilation, no technology has been widely adopted other than increased ventilation. In the winter, this has a thermal impact which must be considered. In ongoing research at Kansas State

University, the locations of fresh air input to the building are being investigated with emphasis on supplying the fresh air to the area where the workers spend most of their time.

In the AAQTF research needs statement for odor (Table 8), Priority #4 has been added to address indoor air quality at agricultural operations. This research need is important and additional funding should be requested to advance the science and technology required to understand the composition, sources, fate of contaminants, and control technologies. Further health effects research is recommended as well.

In the outdoor environment, the impact of flies and other insects on health effects should be investigated. Insects transport microorganisms as they move about. Thus, there is the potential for insects to carry disease from one CAFO to another and from a CAFO to a nearby residential area.

The challenge to the agricultural industry and the agencies which directly serve the industry is to keep current on the research done by the health agencies, monitor their research methodologies, and be very aware of the inferences being made by them from the data and associated statistical conclusions. And, where appropriate, intervene with advice and counsel to these agencies, as well as providing public information if necessary to counter their claims and data.

In addition, the industry must continue to provide a significant level of industry sponsored research to investigate not only production problems associated with livestock, but also the public health concerns. Failure to do so will send a message of non-concern to the general public, and giving them impression that producers do no care about the pressing environmental issues. Research is clearly needed to define the relationships between odor, specific odorants (such as H_2S) and health effects, both on- and off-sites.

It not only will be major good public relations for agriculture to sponsor some of the health affects research, but will bring us the added benefit of being better able to protect the community interest and the health of producers and the process, we need to be doing economic research concerning the cost of making adaptations to provide for reduced adverse health affects.

TECHNOLOGY TRANSFER PROGRAM NEEDS

1. Producers and Private Industry

Producers need to have the opportunity to be educated on proper Best Management Practices (within their industry) to enhance environmental responsibility. These practices need to be based on sound science, not sound bites and emotional rhetoric. Producers have traditionally responded favorably to economically feasible practices that would enhance their production while improving their environmental practices.

EPA's efforts to continue to impose more regulation often do not come from scientific evidence or from a real desire to work with producers to enhance air quality. EPA often appears to be operating from a political agenda that has no practical or legal basis.

From a farmers viewpoint, the process of keeping current and compliant with increasingly complex regulations will increasingly be a major force driving consolidation of farming operations. To survive the environmental planning demands, farmers will increasingly and collectively contract with environmental planning consultants to help keep them "legal" on an ongoing basis. We need to track what is happening to these kinds of incremental costs being imposed on the agricultural industry. Unless we understand the cost consequences of well-intentioned requirements, the regulatory cost burden will handicap successful international market competition, diminish industry incentives to become proactive, and undermine industry support for environmental enhancement programs.

Producers should be provided with a menu of technology delivery mechanisms, including but not limited to publications, web page access, field tours, and demonstration projects. Demonstration projects, for example, will be increasingly valuable in bringing about adaptations to some of our more pressing environmental issues.

We need to be able to demonstrate, on a commercial scale, that some of the remedial ideas are really both technologically and economically feasible. And, if they are not economically feasible, but are technologically feasible, the demonstration projects would assist materially in determining some level of reasonable public assistance for industry participants if they are to adopt technology not justified by the economic status of their businesses. The shorter the time period the public demands for these adaptations, the greater the public assistance need will likely be. In many respects, the primary benefits are to the general public, not to the owner and operator of the farm or ranch business.

CAFO operators in the future will continue to focus attention on feedlot waste management and water and air pollution abatement both for regulatory compliance and for operational improvement (Sweeten, 2000a). Obvious benefits of an increased focus on manure and wastewater management include: 1) control of air pollution (odor and dust); 2) control of surface and ground water pollution; 3) maintain or increase animal productivity by providing well-maintained feedlot conditions that provide all confined animals with a similar production environment; 4) recovery of nutrients in the form of fertilizer, feedstuffs or energy; and 5) maintain or increase efficiency of the CAFO by avoiding operational obstacles such as muddy pen surfaces, excessive stockpiled manure, and underutilized feedlot runoff in holding ponds and settling basins that increase potential for discharges.

2. General Public and Affected Neighbors

When livestock operations were smaller, the industry was much more flexible. Livestock operations could be expanded and contracted with the ebb and flow of economic conditions, and even moved if community development encroached upon them. The affected air shed area was much smaller, and dispersion of odor and other livestock associated problems dissipated in a much smaller geographic area. Far fewer neighbors were affected, and local communities were seldom impacted severely over a long period of time.

However, as economic pressures and technology increased the potential scale of livestock operations, the tonnage of manure and other waste products increased dramatically, the investment capital became millions, and the operations spread over hundreds, and even thousands of acres. Water and air quality concerns of community members mounted significantly as the scale of operations increased, resulting in the community and neighbors taking a much different view of these operations.

Often the operations are no longer "local people", but corporations from "outside" the area. As a result, the local citizens and authorities do not identify personally with the people associated with the livestock operations as much as they might have when the scale of operations were smaller and the proponent was a recognized local family. There is now more "us" vs. "them" political dynamics, with the associated resentments and hostilities, and a lack of understanding of the technology and economic dynamics.

As the scale of livestock operations increases, in order to generate cost efficiencies and maintain lower consumer prices for livestock products, the general public and neighbors of these operations need to be better informed concerning both the reasons for the consolidation, and the consequences (both positive and negative) for the local communities.

As scale of livestock operations increase, the community consequences of these large-scale operations also changes the relationship between the livestock operation and the community. For natural resource based businesses in general, one of the increasing dilemmas is how to implement the ever growing scale of operation without having the negative consequences serve to generate resentment and hostility among members of the community, resulting in costly public relations and political backlash for the livestock operations. It would be far more productive if the exchange of information and concerns were undertaken among the interested parties, with a focus on mutual "opportunity" rather than just "fears" and "paranoia".

Local communities now have such a stake in the development of these large-scale livestock operations that the community might appropriately be considered a "partner" in any such development. Larger scale livestock operations that take such a reality into consideration, and manage their expansion planning with recognition of this local political, social and economic dynamics are bound to develop more community friendly proposals, and meet with less resistance, and quite possibly in the process actually achieve some level of community support in the form of investment incentives.

As a result, it will become increasingly important that new or expanding livestock operations carefully consider the likely impacts, both positive and negative, relative to the community and nearby neighbors. In addition, due to the airshed transport of odors and associated concerns, the idea of "community" must be expanded to include all those persons within the affected airshed, not just the local towns. No longer can a livestock operations operate as if they had an inherent right to do whatever they like on their property. Because of odor transport, the expanding livestock operation must think "airshed dynamics" not just "private property", for they must somehow address the impact of their operations across all parts of the local airshed impacted by their operations.

Legal actions, statewide ballot measures aimed at restricting livestock operations and other activity of community members across the nation clearly signal that local people no long assume they just have to tolerate the consequences of large scale livestock operations. Statewide moratoriums on development of large-scale livestock operations signal that communities are now willing to simply terminate large-scale livestock operations, unless somehow a better way of dealing with unwanted consequences is developed.

For both air and water, all the potential "Beneficial Uses" of the air or water resource must be considered in today's world of environmental concern. Anyone who fails to do so, will likely soon find themselves "nose to nose" with someone who represents one or more other beneficial uses of air or water that is or may be adversely affected by a proposed expansion or development that uses the same resource in an airshed or watershed. The "Community of Interest" must increasingly become a significant part of any large-scale proposal or operation, if the investors and operators wish to solicit community support and understanding.

Increasingly, agriculture is faced with land use planning and zoning regulations to restrict land uses that pose one or more unwanted consequences on the community, especially to neighbors of livestock operations. Increasingly, livestock operations are seen as being little different from any other "factory" or industrial development that has potentially adverse impacts upon the community.

As a result, livestock operations must increasingly make a choice between taking the initiative in dealing effectively with these community concerns, or acting defensively as the community attempts to impose their preferences on the livestock operations, often just shutting them down, or imposing high compliance costs relative to environmental regulations imposed by the community. The concept of "Community of Interest" demands that for mutually beneficial development to take place, with general community support, there must be increased "Community Understanding" of issues, concerns, technology and economics.

One technology needing considerably increased attention relative to livestock operations is the socio-political technologies involved in managing the dynamic interaction between the development proponents and impacted parties, that is, the means by which "listening" and exchanging information can be more productively managed in the course of presenting development proposals to the community.

Since any major expansion of a livestock operation is indeed a "community impact", it will increasingly be necessary for the livestock industry to work with state and local authorities, and sometimes with regional authorities to develop action plans and policy to protect the expansion capability of livestock operations without imposing unreasonable negative impacts on the community. Most likely this will result in the industry together with the greater community developing siting criteria for expanding livestock operations that consider both air quality and water quality concerns, and the associated health impacts, in relation to typical odor and water contaminant transport patterns.

In addition, in order to provide long term protection for the investment in these large livestock facilities, there will likely need to be zoning restrictions in the area that prevent residential and commercial development within some reasonable radius of the livestock operations. "Covenants Not to Sue" may be required additions to property deeds prior to permitting any other development within a certain distance from an already permitted livestock operation. "First

Option to Buy" agreements might be encouraged, in order to allow livestock operations to purchase land within a protective buffer area around a large scale livestock operation, so that buffer areas can expand rather than contract over the longer term.

In some states, Oregon for example, the land use planning process provides a mechanism called a Conditional Use Permit. This permit allows certain kinds of development, but the permit process provides that the operation can only be located on a given site if it complies with certain conditions imposed to protect the interests of the rest of the community, including nearby neighbors as well as watersheds and local communities. These permits are reviewed periodically, and complaints are investigated to determine the extent to which the Conditions are being met, and/or need to be changed. The conditions are designed to protect both the interest of the investors and operators, and the interests of the community, to assure long term mutual benefits, to minimize conflict and to assure compatibility among various land and other resource uses in the area.

Such permitting procedures may seem like a burden to the livestock operations, and they certainly are. In addition, they can delay development, and impose unforeseen costs and difficulties. On the other hand, the permitting process allows all concerned parties to assess the likely impacts of the proposed development, and consider how best to manage those impacts for minimum cost to the community as a whole.

Such a permitting process, if managed well, provides opportunity for public education, for thorough review of the site engineering and operating plans and associated consequences to the general public, especially those living nearby. The result is a livestock operation established on the basis of good public knowledge of what is proposed, a through review of the engineering and consequences, with conditions imposed that reasonably assure the community that their interests will be protected, not only in the short term but in the long term. If a satisfactory mutual conclusion cannot be reached between the proposed livestock operation and the community, then the siting would likely be denied.

Such a permitting process can pose a major dilemma for the proposed livestock operation. Such a permitting process generally complicates the development, at least in the short term, and the process can cost the community a good source of jobs and related local economic activity, especially if the community does not develop an early productive working relationship with the proponents of the development.

On the other hand, by undertaking such a process, both the investors and the local people have the opportunity to assess mutual costs and benefits before hand, and avoid making decisions that might otherwise result in a long term costly running battle between the livestock operation/s and the community, possibly resulting in major investment losses and long term detrimental community circumstances.

In order for future large-scale livestock operations to achieve community support, they can most likely learn a lot from how some of the more successful industrial concerns manage proposed new siting situations. Those organization who do their homework well, who meet with concerned citizens and sincerely take their concerns into account as they engineer the new project, and then make well planned presentations to appropriate community interest groups and authorities, can move through permitting processes efficiently, and end up with a high general level of community support and respect for the proposed project and the people presenting and operating it.

In order to maintain and improve the overall efficiency for large scale livestock and other large scale agricultural operations over coming years, such community focused investment proposal and permitting processes should be studied and considered in relation to legislative and public policy processes, in order to develop more effective interaction between private investment and public concerns in the agricultural industry. The livestock industry should take considerable initiative in this process, to assure that their needs are appropriately addressed relative to the needs and preferences of the overall community of interests in which they must function over the long term.

3. Public Programs

GAO (1999) reported that for fiscal years 1996 through 1998, federal agencies provided a total of $384.7 million in financial and technical assistance to producers for animal waste management. These agencies estimated they would provide about $114 million for this purpose in fiscal year 1999. USDA provided most of this financial and technical assistance -- $326 million or about 85% -- to animal producers through its cost-sharing programs, especially EQIP. In addition, USEPA and USFWS provided 10% and 5% respectively of the financial and technical assistance provided to livestock and poultry producers for animal waste management from fiscal years 1996 through 1998.

Unfortunately none of these fundings specifically address emissions to the air or odors. Even EQIP administered by USDA-NRCS does not directly single out animal air quality issues. However, it does not preclude actions that would assist air quality issues but local officials and farmers have to recognize the need for these actions and prioritize them higher over conservation applications that may be more important for other objectives such as water quality.

Presently most funding is being used for the construction of animal waste storage and disposal systems. There is a need for local officials and farmers to realize that odors and emissions to the air such as hydrogen sulfide should enter into design considerations of such facilities. Also that applied conservation measures for water quality will probably be positive impacts on air quality but probably will not address the air quality issues totally. A holistic planning approach that considers all five resources (soil, water, air, plants, and animals) is recommended.

4. Technical/Engineering Assistance

Holistic approaches that conjunctively control surface and groundwater contamination and also dust and odor emissions while maintaining high confined livestock productivity and health standards will be needed (Sweeten, 2000a). In the last two or three decades, producers, researchers, educators and providers of technical assistance have focused primarily on “obtaining permits” and meeting today’s unsophisticated regulations, rather than on discovering and attaining new levels of technology. One of the chief reasons for this may have been the single-minded USEPA criteria of “no discharge,” which since the mid-1970’s, has focused on surface water protection.

In the future, as research from USDA-ARS and USDA-CSREES provides more complete understanding of “cause and effect” relationships to air quality and production agriculture, holistic approaches become even more important. American farmers can not afford a piece meal approach that would be forced on them by a regulatory command and control system. For example, to design a farm operation to meet permit requirements for water quality at one point in time and then to retrofit that same operation later to meet new requirements for air quality permits will require extensive technical assistance. This appears to be the approach our nation is taking. That logically means that the next major farm legislation must provide increased funding for outreach, information, education, and technical assistance or else expenses for these types of technical services will be another economic burden especially on marginal farmers.

DISCUSSION OF RECOMMENDED PROGRAM ELEMENTS

1. <u>Prioritized Topics</u>
    A. Continue to encourage and provide very significant funding for research to more accurately identify emissions and their real impacts to air quality based on scientific fact, rather than perceptions. This includes developing emission measurements for manure handling systems in all species and phases of livestock production.
        (1) Confined livestock -- open lot systems.
            (a) Corral scraping and stockpiling with periodic removal.
            (b) Composting.
            (c) Open lagoons or holding ponds.
            (d) Covered lagoons utilizing methane recovery as an alternative.
            (e) Land application of manure and wastewater.
        (2) Confined livestock -- enclosed building systems.
            (a) Confinement buildings.
            (b) Liquid manure treatment and storage systems.
            (c) Land application.

    B. Conjunctively address critical points in water and air quality relationships.
        (1) Determine impacts of controlling or reducing emissions with water and air quality jointly.
        (2) Develop holistic systems.

    C. Develop educational programs for livestock producers.
        (1) Explore regional as well as state and national emphasis.
        (2) Adopt currently available research on closely related systems and solutions.
        (3) Provide guidelines to USDA-NRCS and USDA-CSREES for dissemination by Cooperative Extension and producer groups in all applicable states.
        (4) Provide the means by which the national and regional centers and consortia on livestock waste management can operate to pool knowledge and coordinate effects.
        (5) Provide the means and incentives for state-focused research and education programs to operate effectively within the context of state and local conditions and requirements.

D. Incorporate economic assessment of all costs of technology, implementation, and management to the livestock production industry to meet all existing and proposed mandates.

E. Involve the USDA-AAQTF in development of funding and implementation of research, education/extension and technology transfer programs.

2. Partnerships

Partnerships insure the cooperative atmosphere for implementation of practices addressing environmental concerns on the farm. Various cooperative efforts are underway which address air quality issues, including the AgStar program administered by the USDA-NRCS and the federal EPA.

In addition, there is the National Pork Producers Association Stewardship Program which address environmental issues through outreach, education, and implementation. Also, Dairy Quality Assurance Program, a joint agreement between the California Department of Food and Agriculture, Natural Resource Conservation Service, USEPA, and USDA and industry groups.

As legislated in the farm bill, producers have available the Environmental Quality Incentive Program (EQIP) to implement innovative proven control strategies in a cooperative arrangement. Administered through the USDA-NRCS, funds are available to offset the cost of implementing these new control measures.

3. Budgetary Requirements & Recommendations

Congress has provided new funding to USEPA to acquire $80 million for instrumentation to measure $PM_{2.5}$ nationwide but has not provided new funding to allow agriculture to do adequate, sound science to find out causal relationships to allow this industry to be proactive.

In earlier recommendations this Task Force suggested that Congress appropriate annually $20 million for EPA, and $20 million to USDA for air quality research plus $25 million to NRCS for technical assistance directly to local officials. Under the latest MOU between USDA and EPA, it is agreed that these local officials will be the decision makers to decide if applied conservation is adequate to meet the best practices developed in state implementation plans. Local officials need the research to be accomplished in a sound scientific manner and technical information to be available from state Extension and NRCS field personnel.

Specifically, the USDA research funds are to be split equally between CSREES and ARS with at least $8 million for animal (odor and emissions) research. Of the $25 million to NRCS for technical assistance, $4.5 million is recommended for animal issues and $300,000 for training efforts for field staff. These new fundings are desperately needed for agriculture to do its part to improve the health of the American air resource.

4. Implementation – Initiatives, Agency Actions, etc.

With appropriate new funding, ARS has already held pubic meetings to plan a long term agriculture air quality program. Management has identified issues, priority locations across the nation where the problem can be studied and the types of expertise needed to carry out a long term research plan. The only thing that is needed is new funding.

CSREES already has a grant program to the states that have the air pollution problems. Unfortunately, it is less than $1 million per year for all air quality efforts including animal considerations.

At the technical assistance level, both NRCS and Extension funding is lacking. Nationally, less than 11 FTEs are provided for this extremely critical effort. Last year USEPA expanded the non-attainment areas for air quality from 10 to 78 and most of the first 10 were upgraded from moderate to a sever rating.

All the agencies above have attempted to include air quality in their budget proposals. However, with caps at the Secretary's level, that translates to competing with the "Food Stamp Program" or "Meat Inspectors Program." It is hard to argue with starving people that they need clean air. But not many people are starving in America and premature death due to air quality is a reality in America!

SUMMARY

Issues Overview

Animal agriculture in the United States is a $100 billion/year industry. The U.S. is the world leader in efficiency of producing meat, milk, poultry and eggs, largely attributable to increased development of concentrated animal feeding operations (CAFOs). The percentage of domestic livestock in concentrated animal feeding operations varies nationally and regionally from only 10% of the nation's beef cattle inventory to virtually 100% of swine and poultry. CAFOs have been closely regulated for the last 25-30 years under federal and state clean water laws, regulations and policies, and considerable funding has been directed to water quality research, demonstration, education, and technical assistance for CAFOs. Air quality from CAFOs has received only secondary consideration, despite recently increased public concerns and policy attention. Water and air quality protection are inseparable, and the CAFO-related research, technology transfer, and federal and state programs should be linked accordingly and funded adequately, at levels commensurate with public concerns and rapidly-developing scientific expertise at land grant universities and federal laboratories. Producers will need adequate lead-time, cost-effective technologies, and resources to adjust to changing public agendas that include air quality protection.

CAFO Air Quality Parameters

CAFOs including swine and poultry operations, dairies and cattle feedlots, can affect air quality through emissions of: odor, odorous gases (odorants), particulates, and/or some of the so-called greenhouse gases. Sources include: open lots and confinement buildings, manure/wastewater storage or treatment systems, land application, and animal mortalities. Emissions load on the atmosphere is the product of contaminant concentration and airflow rate; and research is underway to develop and demonstrate cost effective ways to reduce either or both these basic components.

Odor from CAFOs sources, as experienced by humans, is the composite of as many as 170 or more specific gases, present in trace concentrations either above or below their olfactory thresholds. Odor is characterized according to: strength (concentration or intensity), frequency, duration, offensiveness, and hedonic tone. Odor strength is measured by various types of dilutions to threshold devices (olfactometers) using human odor panelists; by determining the identity and concentration of individual odor gases; or by electronic "noses", which are in their infancy. Reproducible techniques for odor/odorant sampling, storage and transportation, and presentation to panelists have been developed, yet are undergoing further rapid development worldwide, because of high cost and labor requirements.

Odorous gases of concern today include ammonia and hydrogen sulfide. Considerable research in Europe and more recently in the U.S. has been devoted to monitoring these two fixed gases in and around confinement buildings, partly in relation to animal and human health concerns, and within and around open feedlots and dairies. However, the importance of ammonia and hydrogen sulfide to downwind composite odor as perceived by neighbors is questionable, according to evidence to date. Nevertheless, so-called emissions inventories that include data from often dissimilar systems in Europe have been compiled by EPA and used unwittingly in some states, despite thin and often specious databases.

In the U.S., ammonia emissions have long been encouraged as a legitimate means of balancing the nutrient equation for water quality protection purposes. Feeding and manure/wastewater management systems have been designed accordingly on a widespread basis. A reversal of form of a rather structural nature will be needed as water and air quality protection are now to be viewed conjunctively.

Field and laboratory research has largely focused on measuring concentrations of odor (e.g., odor units (OU)) or odorants (e.g., micrograms/cu. meter, or ppm) in air within and in close proximity to confinement buildings and open lot feeding systems. However, assessments of air quality impact also requires data on:

- emission rates (mass/unit time), e.g., kg/day;
- flux rates (mass/unit area/unit time), e.g., kg/sq. meter/day;
- emission factors (mass/unit of throughput/unit time), e.g., kg/head/year.

The committee has found a substantial number of data sources from the U.S. that provided *concentration data* from swine operations or from laboratory studies involving swine manure; not surprisingly, the preponderance of this data comes from the upper Midwest or from the mid-Atlantic states. Interestingly, ammonia emissions appear to occur with diurnal fluctuations, while hydrogen sulfide emissions occur in bursts from anaerobic storages or lagoons. To a lesser extent, similar data exists from poultry (Midwest and Southeast), dairy (Midwest, Northeast, and West Coast), and beef feedlot operations (Southern Great Plains and West Coast). However, a paucity of data exists on *emission rates, flux rates,* and *emission factors* from these sources and the many different manifestations of manure and wastewater management systems within each species. Where such data has been reported, it shows a wide range; consensus numbers appear elusive. Further research by well-qualified and well-equipped laboratories is needed as a precursor to rational attempts to develop policies for CAFO odor and odorants.

It is believed that future research will be directed toward odorous gases that more closely correlate with odor as perceived by humans--the discerning public. Candidate compounds may include volatile organic compounds (VOCs) such as the volatile fatty acids, amines, alcohols, aliphatic aldehydes, p-cresol, indole, skatole, or mercaptans. The above admonitions on data quality and standardization of useful expression will apply as alternative compounds are studied and attempts made to relate them to odor.

It has long been known that carbon dioxide and methane (non-odorous fixed gases of digestion and organic matter decomposition) are produced both by confinement and range/pastured livestock and poultry. Refinements in animal rations have improved digestibility, reduced manure loads, and shortened the production interval of meat animals, and thereby contributing to lowered emissions. With appropriate incentives for adoption, known technology for energy recovery from liquid manure treatment systems, together with state-of-the art open lot manure and holding pond management practices, may be able to further reduce emissions of these so-called greenhouse gases, which are not part of the regulatory fabric regarding air quality.

Unlike odor and odorants, particulates have been explicitly regulated as one of six criteria pollutants under the Federal Clean Air Act since the 1960's. Total suspended particulate (TSP) standards for ambient air quality were replaced by PM_{10} standards in 1987, and recent USEPA proposals have addressed fine ("respirable") particulate, regarded as $PM_{2.5}$. Particulate sources from CAFOs include: feedmills, feedstuffs storage and handling areas, open lots, confinement buildings, roads and alleys, manure handling, solid manure storage or composting areas, and land application. Except for feedmills, these sources have been regarded as fugitive emission sources.

Emission Factors

Stemming from old TSP databases developed for other purposes, USEPA and its contractors of the 1970's extrapolated and subsequently synthesized original emission factors (published in AP-42) that have since been proved atypical by subsequent research. Refinements are in progress based on more accurate recent data that includes actual PM_{10} field measurements and modeling for cattle feedlots in the Southern Great Plains, where over 75% of he nation's beef cattle are fed for slaughter. Attempts to extrapolate air quality data from beef cattle feedlots for dairy applications or vice versa are ill-advised. It has proved inordinately difficult to correct poorly-conceived emission factors, notwithstanding new, superior data. Therefore, improved processes for updating emission factors for an array of CAFO-related air contaminants in the future should be developed.

Available data bases on $PM_{2.5}$ for CAFOs are very thin or nonexistent, although a few laboratories are becoming equipped to supply this data in the future for dairies and feedlots (California and Texas, for example). Evidence exists of rapid, predictable fluctuations of PM concentrations from open lot and animal confinement buildings alike owing to periods of heightened animal activity as triggering mechanisms, over and above more or less basal PM emission levels, possibly suggesting future topics of research and innovation, along with conventional control technologies.

Human Response and Health Effects

Concerns with health effects of odor, odorants, and PM from CAFOs extend to livestock health/performance issues, and to humans working within or living in proximity to such facilities. These health-related issues, and applicable prevention technologies, may or may not be coupled. It appears that confinement swine facilities have been the focus of most of the research to date, followed perhaps by the poultry industry, as confinement buildings are the sites of highest air contaminant concentrations and exposure durations. One of the artifacts of increased animal concentration and industry consolidation may be an increased industry capacity to address both the on-farm as well as off-farm issues regarding potential health effects. Recent evidence suggests greater secondary health effects on frequently-exposed neighbors than previously documented, insofar as confined swine operations are concerned.

Current Federal and State Policies

Federal and state policies regarding CAFOs have been in existence for decades. Water quality concerns were addressed in the Federal Water Pollution Control Act of 1972, which listed CAFOs as point sources. Accordingly, federal effluent limitation guidelines (ELGs) and National Pollutant Discharge Elimination System (NPDES) or state-equivalent permits soon followed, and these were one-dimensionally focused on protecting surface water quality through no-discharge requirements. As documented in this report, individual States, and more recently USEPA regions (e.g., Region 6), subsequently have followed suit by adopting a virtual patchwork of tailored policies and regulations that have attempted to address voids of groundwater protection and nutrient management, and in a minority of cases air quality concerns, that were not addressed in USEPA’s 1974-76 ELGs, which are still in effect. It is notable that USEPA plans to release new ELGs for CAFOs in December 2001; presumably, these may level or at least straighten out the playing field to a certain extent.

Integrated Programs

USDA agencies, land grant universities, and private industry associations, often times in partnerships with USEPA, local soil and water districts, and state environmental protection agencies, have launched coordinated research, education, training, technical and financial assistance programs to address water quality concerns and to enable the progressive attempts of CAFO operators to design and operate manure and wastewater management systems that address extant public policies as well as improve performance, productivity, beneficial use of nutrients, and minimize liability with respect to neighbors. Despite lingering problems in some areas or specific watersheds and notwithstanding public funding limitations, these programs plus the infusion of massive private investments on the part of CAFO operators have largely addressed the nation’s water quality concerns and kept enormous quantities of manure and wastewater from being discharged off site and into streams, but rather put to beneficial use on crop or pasture land either on- or off-premises. Current or previous partnerships include the USDA interagency Water Quality Initiative, USDA/NRCS EQIP program; the National Pork Producers Council’s Environmental Quality Assurance Program; and the new USDA/USEPA Unified National Strategy for Animal Feeding Operations, which will involve development of comprehensive nutrient management plans (CNMPs) for CAFOs. These are laudable programs.

However, no integrated counterpart programs to address air quality from CAFOs have been funded or developed. As a result, many operators may have facilities or systems optimized for water quality protection, but non-optimal with respect to emerging air quality objectives. It will take considerable time, investment, and a full measure of integrated, coordinated programs of research, education, training, technical and financial assistance to address air quality concerns adequately and co-extensively with water quality protection. Recent reactive, enforcement-related forays to target selected, individual operations with exposure to hazardous waste regulations designed for industry other than animal agriculture appear ill-conceived and counter to the systematic development and progressive implementation of an array of technologies that can ultimately find pervasive adoption by the CAFO industry of scientifically-sound, appropriate air pollution control technologies. Just as the defense sector recognizes that having missiles and knowing when to use them require two different hierarchies of thinking; the same is true of copious environmental policies.

Odor Control Technologies

How can odor and odorants be satisfactorily controlled? There are four basic approaches, with multiple technologies that have possibilities within each approach:

- Ration/diet manipulation -- reduced protein levels; improved carbohydrate, nitrogen and sulfur utilization; synthetic amino acid supplementation; improved energy balances; copper supplementation (swine only); etc.
- Manure treatment -- aerobic conditions in surface manure (feedlots); drainage; frequent manure harvesting; lightly-loaded/facultative lagoons; multiple stage lagoons; surface aeration of lagoons or storage pits; experimental biochemical amendments; etc.
- Capture and treatment of emitted gases -- reduced liquid manure surface area; wet or dry scrubbers; dust control; biofilters; lagoon or storage pits covers; chemical oxidant surface sprays; non-thermal plasma reactors; etc.
- Enhanced dispersion -- excellent site selection; absence of confining valleys; adequate buffer distance; tree barriers; deflection walls (air dams); exhaust stacks; dispersion modeling; etc.

It should be cautioned that some of these technologies are as yet experimental in nature, or practical applications may not have been demonstrated. Likewise, selection of control technologies should be tailored to sources within site-specific circumstances that include facility design and management factors, climate, topography, and potential receptors.

Dust Control Technologies

Likewise, technologies for particulate (dust) control from open-lot feeding systems are available and include: frequent manure removal, stocking density adjustment to take advantage of excreted manure moisture, and where needed water sprinkling. Use of vegetable oil sprays has been demonstrated for use in swine confinement buildings, and terpenic sprays has reduced airborne bacterial infections in calf confinement barns. Speciation of CAFO-related dusts in contrast with ambient dusts from upwind operations (e.g., field dust from crop production operations) have not been determined heretofore.

Research Programs Needs: Health Effects

Worker health from exposure to dust, odor and odorants inside swine confinement facilities has received most of the attention regarding health-related issues of CAFOs. Respiratory diseases or conditions are generally more common among swine confinement building workers than among cohorts not similarly exposed. Commonly used design and management practices have been altered accordingly.

Recent attention has been paid to health complaints of rural residents neighboring large-scale swine confinement operations, with preliminary signs of mood states such as tension, anger, depression, or fatigue showing up recently in community surveys or epidemiological studies. Hydrogen sulfide is a suspected contributor. Linkages, if any, between concomitant control of odor, hydrogen sulfide, or any other specific gases, should be examined in future studies.

Research Funding Levels

Funding levels for air quality research regarding CAFOs are elusive. While the GAO reported agency investments in a wide array of animal waste-related research -- USDA-ARS an average of $5.65 million per year (FY96-99) and USDA-CSREES reportedly $6.9 million in FY97 -- the amounts attributed to air quality were not reported separately, and are considered a small fraction of these totals. USEPA investments in agricultural air quality research are not reported and are likely miniscule. Both USDA and USEPA need to come to the table with enhanced long-term funding packages and programs for agricultural air quality research and technology transfer that specifically address CAFOs.

Research and Technology Transfer Needs: An Assessment

Numerous research and/or technology transfer needs and opportunities were mentioned in the text of this report. In brief, these include:

- Develop accurate and broadly applicable emission concentrations, rates, and emission factors for PM, odor and specific odorants applicable to CAFOs;
- Define emission rates as a function of diurnal, seasonal, and climatic variations, as well as design and management practices;
- Develop effective, practical odor control technologies for confined animals, treatment, and land application systems;
- Determine relationships among odor, odorants, particulates and airborne microbial species;
- Identify kinetic release mechanisms for odorants and odor from principal manure sources;
- Target the development of control technologies that will specifically address the odor/odorant kinetic release mechanisms;
- Develop practical ways, capable of widespread adoption, of reducing ammonia from CAFOs;
- Effectively transfer appropriate technologies for odor control to producers;
- Develop innovative air treatment processes for confinement building exhausts or covered lagoon surfaces;
- Develop odor reduction treatments for application immediately prior to land application;
- Develop accurate standardized measurement technologies for odor, odorants of principal concern, and fine particulate, and ensure these systems become widely available for research and demonstration; this should include electronic measurement devices that are well-correlated with the human odor experience;

- Develop accurate dispersion models for odor, odorants, and PM appropriate to specific types of CAFOs, addressing the inherent problems of Gaussian models;
- Characterize air quality as a function of distance from large CAFOs;
- Implement cooperative industry/agency/university programs for scientific evaluation of new products for producers' consideration and adoption;
- Assess the importance of indoor air quality at CAFOs and devise ways to reduce exposure levels;
- Devise suitable acceptability criteria for community-level exposure to odor and specific associated gases;
- Assess potential relationships between emission constituents, concentrations, and potential health indicators, and devise appropriate mitigation strategies accordingly;
- Monitor studies by traditional health organizations and centers and identify implications for the CAFO industry, developing partnerships to proactively address any identified issues.

Programmatic, Industry, and Community Relationships: A Discussion

In summation, air quality agencies need to recognize that the U.S. excels and will continue to excel in animal agriculture. Industry consolidation is a response both to securing positions of high productivity and adjusting to widely-recognized and increasing environmental protection responsibilities. Producers need to recognize that those technologies that were optimized for water quality protection may now seem insufficient for protecting air quality, which tends to be even more regionalized in terms of problems and solutions. Margins of community acceptance that were present when animal feeding operations were dispersed and small (by today's standards) with individual farmer ownership may no longer exist as operations grow by orders of magnitude and become more complex in structure. Nor will relatively straight-forward technologies for controlling water pollution likely be considered adequate for the more complex air quality issues. Fortunately, there are promising technologies either available or being developed that can significantly reduce emissions of odor, odorants, or dusts, as appropriate. None of these technologies are free or even especially cheap; but neither are alternative legal remedies. Partnerships among industry, agencies, universities, research and technology transfer institutions, and the public will be the best and longest-lasting means of abating CAFO air quality problems that exist in parts of the country or in isolated instances. The nation remains far under-invested in development of technologies to assess and abate air contaminants from CAFOs, and as such seems in danger of reacting inappropriately with policies that are far ahead of the science or industry's ability to adapt in a timely fashion.

A program of accelerated research, education, technical training, technology transfer, and financial assistance to cope with CAFO air quality problems is strongly recommended. The USDA Agricultural Air Quality Task Force, established under the 1996 Farm Bill, has a stake in designing and fostering the implementation of these proactive, progressive programs.

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Table 1. Comparison of Animal Emission Factors (kg NH_3/animal/yr) Battye et al. (1994).

	Asman (1992)				Buijsman et al. (1987)	NAPAP (1990)	Battye et al. (1994) composite
Animal	Stable + storage	Spreading	Grazing	Total			
Cattle (beef & dairy)	7.396	12.244	3.403	23.043	18.	12.6	22.9
	(1.6-12.9)	(3.6-21.2)	(2.8-8.2)	(5.2-39.7)			
Swine	2.521[a]	2.836[a]	0	5.357[a]	2.8	3.35	9.1
	(2.4-8.1)	(2.8-8.0)	0	(5.2-16.1)			
Poultry (chickens, turkeys, ducks, etc.)	0.095	0.154	0	0.249	0.26	0.071	0.179
	(0.05-0.64)	(0.10-0.64)	0	(0.12-1.8)			
Horses	3.9	3.6	4.7	12.2	9.4	--	--
Sheep (ewes)	0.381	0.693	0.623	1.697	3.1	1.85	3.37

[a] Battye et al. (1994) stated that these composites appear to have been calculated using the incorrect number of swine in the Netherlands and are therefore too low; corrected values would be 4.0, 4.5, and 8.5 respectively.

Table 2. Measured Ammonia Flux Rates and Emission Factors from North Carolina Swine Lagoon (Aneja et al., 2000a).

	Average Daily Ammonia Flux Rate, ΦgN/m^2/minute			Emission Factors
Month	Mean ±SD	Max	Min	Kg/hd/yr

August 1997	4,017 ± 987	8,526	2,358	5.2
December 1997	844 ± 401	1,913	369	1.1
February 1998	305 ± 154	695	90	0.4
May 1998	1,706 ± 552	3,594	851	2.2
Average	1,718 ± 523			2.2

Table 3. Current USEPA National Ambient Air Quality Standards (NAAQS).

Criteria Pollutant	Averaging Time	Concentration
1. Particulate Matter (PM10)		
Primary	Annual arithmetic mean	50 $\mu g/m^3$
Primary	24-hour	150 $\mu g/m^3$
2. Carbon Monoxide		
Primary	1-hour*	35 ppm
Primary	8-hour*	9 ppm
3. Nitrogen Dioxide		
Primary	Annual arithmetic mean	0.053 ppm
Secondary	Same as primary	Same as primary
4. Sulfur Dioxide		
Primary	Annual arithmetic mean	0.03 ppm
Primary	24-hour*	0.14 ppm
Secondary	3-hour*	0.5 ppm
5. Ozone		
Primary	8-hour	0.08 ppm
Secondary	Same as primary	Same as primary
6. Lead		
Primary	Calendar quarter	1.5 $\mu g/m^3$

* This concentration is not to be exceeded more than once per year.
ppm = parts per million, $\mu g/m^3$ = micrograms per cubic meter

Table 4. Emission calculations for four dairies (California) using emission factors of 70, 15, and 4 lbs/1000hd/day.

Dairy Facility Parameters	**Dairies**				**Totals**
	A	**B**	**C**	**D**	
Land Area (acres)	857	1,013	2,174	5,534	9,398
Milk Cows	3,931	4,597	10,348	24,803	43,679

Calves	3,629	4,244	9,552	22,896	40,321
Total Herd	7,560	8,840	19,900	47,700	84,000
Area per head (ft^2/hd)	1115	976	947	985	-
Annual PM$_{10}$ emission based on 70 lbs/1,000 hd/day (cows only), tons	50	59	132	317	558
Annual PM$_{10}$ emission based on 15 lbs/1,000 hd/day (cows only), tons	11	13	28	68	120
Annual PM$_{10}$ emission based on 4 lbs/1,000 hd/day (cows only), tons	3	4	8	18	33

Table 5. Cattle feedyard emission factors determined using the ISC3 model and the modified Peters and Blackwood (1977) approach, referred to as the TAMU procedure (McGee, 1997).

Feedyard	**Mean, Net 24-hour Measured Concentrations TSP**	**ISC3 Modeled Emission Factors TSP**	**TAMU Procedure modeled Emission Factors TSP**	**TAMU Procedure Emission Factors PM$_{10}$**
	(µg/m^3)	(lbs/1000hd/d)	(lbs/1000hd/d)	(lbs/1000hd/d)
A (45,000 hd)	589	97	103	26
B (42,000 hd)	267	50	48	12
C (17,000 hd)	363	96	103	26
Grand Mean	412*	81	82	20

* 412 µg/m^3 is the grand mean of the downwind minus upwind concentrations reported by Sweeten et al. (1988) and is not intended to represent the mean of the column.

TABLE 6. MATRIX OF CANDIDATE ODOR/ODORANTS CONTROL PRACTICES FOR CONCENTRATED ANIMAL FEEDING OPERATION

USDA-AAQTF, Confined Livestock Air Quality Subcommittee

		ODOR SOURCE OR LOCATION				
POTENTIAL CONTROL APPROACHES		Confinement Facilities Bldgs./open feedlots	Treatment/System (Solid/liquid)	Storage (Solid/liquid)	Land Application (Solid/liquid)	Dead Animals/ Mortality
1. RATION MANAGEMENT		Bio-Additives	Bio-Additives	Bio-Additives		
		Chem. Additives	Chem. Additives	Chem. Additives	Reduced P	N.A.
		Reduced Protein	Reduced Protein	Reduced Protein		
		High lysine				
2. TREATMENT METHODS						
	a. Aerobic	Mechanical aeration	Mechanical Aeration	Mechanical Aeration	Mechanical Aeration	Composting
		Flush system	Natural aeration	Composting	Composted manure	
		Scraper system	Thin-layer aeration			
			Facultative lagoon			
	b. Anaerobic	N.A.	Lightly-loaded lagoon (VS)	Mesophilic digester	2nd-stage trt. effluent	Mesophilic digeste
			Mesophilic digester	Thermophylic digester		Thermophylic dige
			Thermophylic digester			
			Sequencing batch reactor			
	c. Chemical/biochemical	Bio-Additives	Bio-Additives	Bio-Additives	Chem. Additives	Acidification/liquic
		Chem. Additives	Chem. Additives	Chem. Additives		Freezing
			Electrical current (e)			
			Nonthermal plasma (e)			
	d. Thermochemical	N.A.	Combustion	N.A.	N.A.	Incineration
			Gasification/pyrolysis			Rendering
			Fuel cell			
3. CAPTURE/TREAT ODOR/ODORANTS		Scrubber, wet	Covered lagoon	Covered storage	Soil injection	Covered process
		Scrubber, dry	Anaerobic digesters	Contained storage	Disking w/ surface spread	
		Biofilter	Crust formation	Crust formation		
			Biofilter	Biofilter		
4. ENHANCED DISPERSION		Trees/Agri-forest	Trees/Agri-forest	Vented storage	Mid-day application	Trees/Agri-forest
		Windbreak wall/Air dam		Trees/Agri-forest	Trees/Agri-forest	Stack
		Elevated source				
		Site Selection				

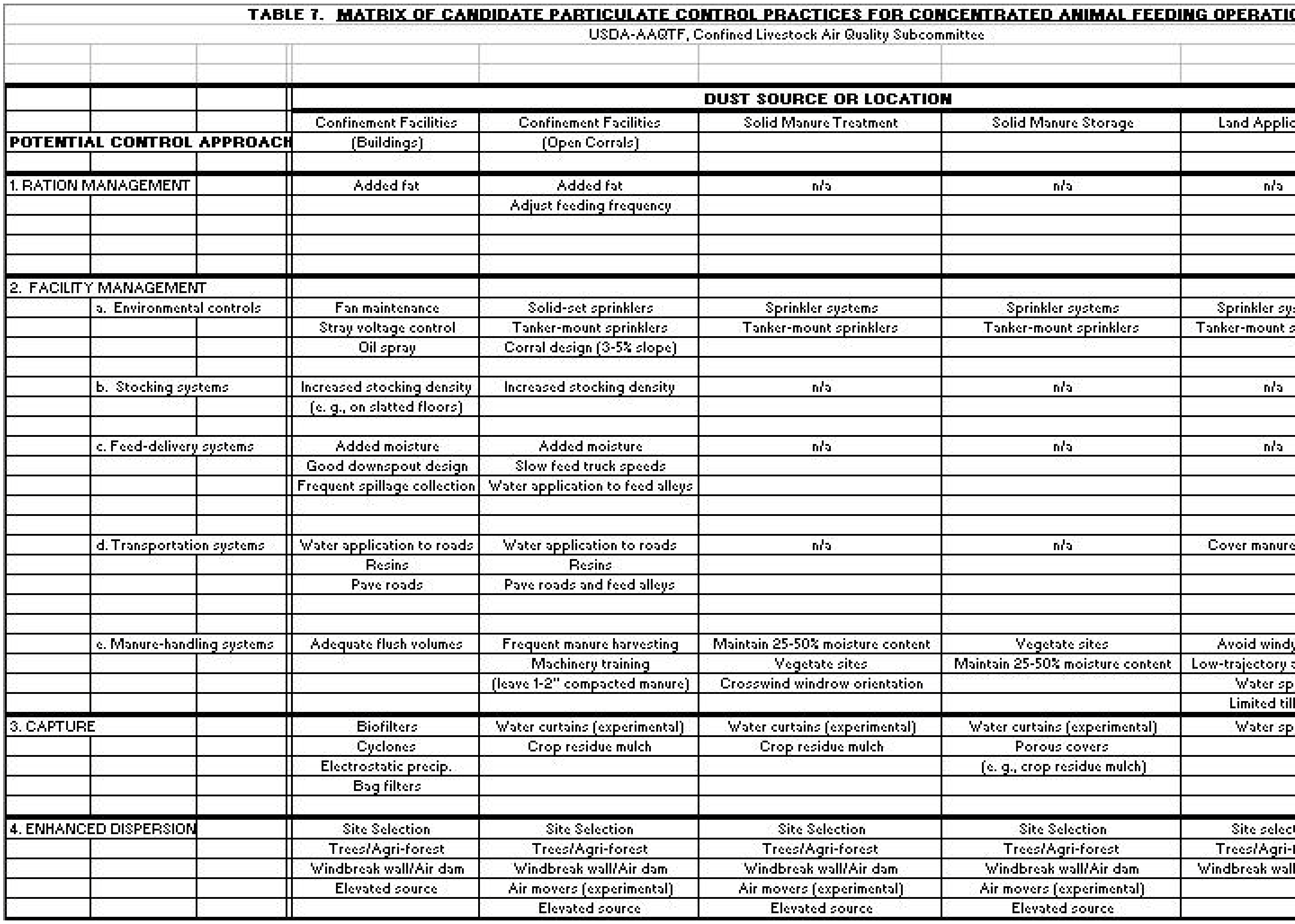

TABLE 7. MATRIX OF CANDIDATE PARTICULATE CONTROL PRACTICES FOR CONCENTRATED ANIMAL FEEDING OPERATIO

USDA-AAQTF, Confined Livestock Air Quality Subcommittee

		DUST SOURCE OR LOCATION				
		Confinement Facilities	Confinement Facilities	Solid Manure Treatment	Solid Manure Storage	Land Applic
POTENTIAL CONTROL APPROACH		(Buildings)	(Open Corrals)			
1. RATION MANAGEMENT		Added fat	Added fat	n/a	n/a	n/a
			Adjust feeding frequency			
2. FACILITY MANAGEMENT						
	a. Environmental controls	Fan maintenance	Solid-set sprinklers	Sprinkler systems	Sprinkler systems	Sprinkler sy
		Stray voltage control	Tanker-mount sprinklers	Tanker-mount sprinklers	Tanker-mount sprinklers	Tanker-mount s
		Oil spray	Corral design (3-5% slope)			
	b. Stocking systems	Increased stocking density	Increased stocking density	n/a	n/a	n/a
		(e. g., on slatted floors)				
	c. Feed-delivery systems	Added moisture	Added moisture	n/a	n/a	n/a
		Good downspout design	Slow feed truck speeds			
		Frequent spillage collection	Water application to feed alleys			
	d. Transportation systems	Water application to roads	Water application to roads	n/a	n/a	Cover manure
		Resins	Resins			
		Pave roads	Pave roads and feed alleys			
	e. Manure-handling systems	Adequate flush volumes	Frequent manure harvesting	Maintain 25-50% moisture content	Vegetate sites	Avoid windy
			Machinery training	Vegetate sites	Maintain 25-50% moisture content	Low-trajectory s
			(leave 1-2" compacted manure)	Crosswind windrow orientation		Water sp
						Limited till
3. CAPTURE		Biofilters	Water curtains (experimental)	Water curtains (experimental)	Water curtains (experimental)	Water sp
		Cyclones	Crop residue mulch	Crop residue mulch	Porous covers	
		Electrostatic precip.			(e. g., crop residue mulch)	
		Bag filters				
4. ENHANCED DISPERSION		Site Selection	Site Selection	Site Selection	Site Selection	Site select
		Trees/Agri-forest	Trees/Agri-forest	Trees/Agri-forest	Trees/Agri-forest	Trees/Agri-f
		Windbreak wall/Air dam	Windbreak wall/Air dam	Windbreak wall/Air dam	Windbreak wall/Air dam	Windbreak wall
		Elevated source	Air movers (experimental)	Air movers (experimental)	Air movers (experimental)	
			Elevated source	Elevated source	Elevated source	

Table 8. Recommended research program related to air quality regulations of agricultural odors.

Objectives/*Sub-Objectives*	Recommended Support	CAFO Related
Agricultural odors remain a complex issue with both a measurable component based on the presence of small amounts of specific gas molecules and a more subjective component based on individual sensitivity. Support for expanded research activities is needed to fill the gaps between technology development and the needs of agricultural producers and the public.	$2 M/yr	✓
Expanded research support is required in the following areas to better identify and measure odors, determine the relationship between odorous compounds and the environment, identify human response to odors, and identify economical control methods and reduction strategies. ▪ *Determine whether odors or specific odorants are useful measures of other contaminants that are more difficult to detect. Determine relationships between biological particulate matter and odors as a function of distance from a site.*	$1 M/yr	✓

Determine odor sources from agricultural production and the impact of design and management practices on odor release and transport. ▪ *Develop understanding of chemistry of anaerobic impoundments and develop new methods that can reduce odors and enhance treatment. (Example -- development of inexpensive cover that is an aerobic biological reactor which oxidizes hydrogen sulfide and ammonia.)*	$1 M/yr	✓
Improved dispersion modeling methodology including odor release, transport, and receptors. ▪ *Determine whether air quality beyond property lines may be improved by using structural barriers, trees and other vegetation to adsorb odors and chemicals and potentially enhance dispersion.*	$1 M/yr	✓
Standardized measurement methodology, technologies and devices for odor detection including frequency, intensity, duration, and offensiveness.	$1 M/yr	✓
Determine the chemical and physical properties of odor including odor production processes, interaction of environmental variables, odor release pathways, interactions among odorants, and kinetics. ▪ *Assess potential relationships between emission constituents and their concentration levels and health symptoms of neighbors.*	$1 M/yr	✓
Development and implementation of economically and technologically feasible odor control and reduction strategies. ▪ *Develop technologies to reduce odors and emissions for housed animals, treatment and land application systems.*	$1 M/yr	✓
Priority #3 Total = $8 million/year		

These recommendations are based on several meetings of the Agricultural Air Quality Task Force, analysis of existing research and a review of the literature.

▪ *Modified by addition of draft Sub-Objectives,* Confined Animal/Livestock Air Quality Subcommittee, November 1999.

APPENDIX A

Assumptions and Errors Incorporated in Development of Original EPA AP-42 Emission Factor for Cattle Feedlots

(Parnell, 2000)

The only science base for the EPA AP-42 PM_{10} emission factor for cattle feedyards was Peters and Blackwood (1977). Peters and Blackwood used the following assumptions in their development of a cattle feedyard emission factor:

- The infinite line source Gaussian model would be the most appropriate model to back-calculate an emission factor. The equation representing the infinite line source model is as follows (Wark and Warner, 1981):

$$C_{10} = \frac{2Q_L 10^6}{\sqrt{2\pi}\left(\sigma_z u\right)} e^{\left(-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right)}$$

(Eq 1.)

where:

C_{10} = steady state concentration 'x' meters downwind from the source, micrograms per cubic meter ($\mu g/m^3$) (This concentration is assumed to be a 10-minute concentration because the spread parameters associated with Gaussian dispersion modeling (σ_y and σ_z) were based upon 10-minute concentration measurements.);

Q_L = emission rate, grams per meter per second (g/m/s);

σ_z = vertical spread parameter, meters (m) (This parameter is a function of downwind distance 'x' and atmospheric stability.);

u = average wind speed, meters per second (m/s); and

H = height of emission, m.

- downwind distance 'x' was 50m (best estimate);
- wind speed (u) was 4.47 m/s (national average);
- stability class was 'C'(national average);
- height of emission (H) was 3.05 m (10 feet);
- vertical spread parameter (σ_z) was 4m {$\sigma_z = 61(.05)^{.911}$};
- Peters and Blackwood converted the reported 24-hour concentrations reported by Algeo et al (1972) to 10-minute concentrations using the model recommended in Wark and Warner (1981) as follows:

$$C_{10} = C_{1440}\left(\frac{1440}{10}\right)^{0.17} = 2.33C_{1440}$$

- It was assumed that there were an average of 8,000 head on each feedyard. This was the average number of cattle on all feedyards in California. It was also assumed that the cattle spacing was 150 square feet per head and the yards were square. These assumptions resulted in a source that was 334 meters square. They used a square feedyard with 330 meters on each side. Equation 1 can be simplified by inserting the assumptions specified above as follows:

$$C_{10} = 0.0446 \bullet 10^6 Q_L (0.748) = 0.0334 \bullet 10^6 Q_L$$

Solving for Q_L, we get the following:

$$Q_L = 30 \bullet 10^{-6} C_{10}$$

(Eq. 4)

A thorough analysis of the Peters and Blackwood (1977) report yielded the following:

- Peters and Blackwood made a mistake in calculating their reported Q_L values. They calculated the Q_L for the average net downwind concentrations for each of the 25 feedyards reported by Algeo et al., using an equation similar to equation 4 but their coefficient was 24.2 $*10^{-6}$ instead of 30 $* 10^{-6}$. (We were unable to determine why they used the different number.) They used equation 5 instead of equation 4.

$$Q_L = 24.2 \bullet 10^{-6} C_{10} \tag{Eq. 5}$$

Our initial thought was that they had revised their assumption and that the height of the emitting source was zero meters instead of 3.05 meters. This would seem logical since the source is a ground level source. If H = 0, the coefficient in equation 4 is 22.4 * 10^{-6}. We feel that a more appropriate calculation of Q_L would be equation 6.

$$Q_L = 22.4 \bullet 10^{-6} C_{10} \tag{Eq. 6}$$

- The overall average, measured, net downwind concentration reported by Algeo et al (1972) was 654 μ g/m^3. Converting this 24-hour concentration (C_{1440}) to a 10-minute concentration (C_{10}) using equation 2, we get 1485 μ g/m^3.
- Using 1624 μg/m^3 in Equation 5 as Peters and Blackwood (1977) did, we get Q_L= 0.036 grams per meter per second (g/m/s).
- Peters and Blackwood (1977) did not know the number of head of cattle that were on each of the 25 feedyards used in the Algeo et al. (1972) study. They assumed that the average number of cattle on the 25 feedyards was 8,000 head and that each yard was square. With the spacing of 150 square feet per head, the yard would be 330m by 330m. They calculated the cattle feedyard emission factor (EF) as follows:

  EF=(0.036 g/m/s ∗ 330 m ∗ 3600 s/h ∗ 24 h/d)/(454 g/lb ∗ 8) =283 lbs/1000hd/d (TSP)

- If the emission rate (Q_L) had been calculated with equation 6 (H=0) which we feel was more appropriate since the source of PM was at ground level (H=0), Q_L = 0.033 g/m/s. The cattle feedyard emission factor (EF) with a Q_L = 0.033 g/m/s is 259 lbs/1000hd/d (TSP).
- Grelinger and Lapp (1976) reported a personal communication with Algeo where he indicated that the average number of head of cattle on the yards he sampled were 20,000 to 25,000 instead of 8,000. Using 0.033 g/m/s and average number of 22,500 head on each square feedyard with dimensions of 560m by 560m, the cattle feedyard emission factor is 156 lbs/1000hd/d (TSP).

In summary, Peters and Blackwood (1977) did the best they could with the available reported information to develop a cattle feedyard emission factor. They made a mistake in their calculation of the emission factor. Had they performed their calculation correctly and found out that the average number of cattle on feed was 20,000 to 25,000 head, they would have had an emission factor of 156 lbs/1000hd/d (TSP) instead of 280 lbs/1000hd/d (TSP). We felt that there were too many assumptions and guesses in Peters and Blackwood's development of the AP-42 emission factor. We needed better data for concentrations measurements, meteorological conditions, and number of head of cattle at the yards while sampling in order to develop a more accurate PM_{10} emission factor.

Texas Cattle Feedlots Particulate Study

Although, Peters and Blackwood (1977) made errors in their development of a cattle feedyard emission factor, they did develop a procedure for back-calculating cattle feedyard emission factors from measured, net, 24-hour downwind concentrations of TSP. The modified Peters and Blackwood procedure is as follows:

- Calculate C_{10} with Equation 2;

- Calculate Q_L with equation 6;
- Determine the side dimension ‘W’ in meters assuming that the cattle have a spacing of 150 ft^2/head
- Use Equation 7 to calculate ‘EF’ in lbs/1000hd/d (TSP).

Sweeten et al. (1988) reported 24-hour sampling data from Texas feedyards with capacities of 45,000, 17,000 and 42,000 head of cattle. One of the significant findings of this study was the PM_{10}/TSP ratio. The average PM_{10}/TSP ratio was reported to be 25%. EPA accepted this ratio and most SAPRA use the PM_{10} emission factor of 70 lbs/1000hd/d ($\frac{1}{4} * 280$).

Parnell et al. (1999) reported results of a study funded by the TNRCC that a more accurate annual PM_{10} emission factor would be 15 lbs/1000hd/d. This factor was the result of a study that included sampling, back-calculating emission factor using ISC3 and annualizing the result by a factor of 0.79. The average number of cattle on the three yards reported by Sweeten et al. (1988) was 35,000 head. If this average feedyard (35,000 head) were square, it would have an average side dimension (W) of 700m by 700m. The average 24-hour concentration was 412 $\mu g/m^3$ (TSP). Using a similar procedure, $C_{10} = 959\ \mu g/m^3$ (TSP) (Eq. 2), $Q_L = 0.0215$ g/m/s (Eq 6.), and the emission factor would be 82 lbs/1000hd/d (TSP). Using 25% of TSP = PM_{10}, we would have a PM_{10} emission factor of 20 lbs/1000hd/d. If we annualize this by multiplying by 0.79 accounting for rainfall events, we get 16 lbs/1000hd/d (PM_{10}). Although we have used a very different and more complicated method in our study for the TNRCC, our resulting emission factor was 15 lbs/1000hd/d (PM_{10}). The resulting emission factor 16 lbs/1000hd/d (PM_{10}) was very nearly the same using the modified Peters and Blackwood procedure.

In summary, we have found significant errors in the EPA report (Peters and Blackwood, 1977) that is the basis for the AP-42 emission factor for cattle feedyards. We have used Peters and Blackwood’s procedure with H=0 for a ground level source instead of an emission source 10 feet in the air; used an infinite line source model with the concentrations reported by Sweeten et al. (1988, 1998); and determined that the emission factor should be 20 lbs/1000hd/d PM_{10} (uncorrected for rainfall events) or 16 lbs/1000hd/d (annualized). The TAMU process for obtaining cattle feedyard emission factors from 24-hour, measured, net downwind concentrations is as follows:

1. Convert 24-hour TSP concentration to 10-minute TSP concentration using equation 2.
2. Calculate the emission rate (Q_L) using equation 6 (H=0).
3. Determine the side dimension (‘W’ meters) of a square yard with 150 square feet per head for the feedyard having ‘N’ thousand head. .
4. Use equation 7 to calculate the cattle feedyard TSP emission factor (EF) in units of lbs/1000hd/d.
5. Multiply the TSP emission factor (EF) by 0.25 to obtain the PM_{10} emission factor.
6. Annualize the PM_{10} emission factor by 0.79.

$$EF = 190 Q_L \frac{W}{N} \qquad \text{(Eq 7.)}$$

APPENDIX B

ASAE Standards

- **Control of Manure Odors**
- **Design of Anaerobic Lagoons for Animal Waste**

APPENDIX C

Glossary of Acronyms

Appendix C

GLOSSARY OF ACRONYMS

1. General Terms

AAQTF = USDA Agricultural Air Quality Task Force
AED = aerodynamic equivalent diameter
AFOs = animal feeding operations
ARB = Air Resources Board
ARDS = Acute Respiratory Distress Syndrome
ASAE = American Society of Agricultural Engineers
ASTM = American Society of Testing and Materials
BBACT = Baseline Best Available Control Technology
BMP = best management practice
CAAA = Clean Air Act Amendments
CAFOs = concentrated animal feeding operations
CARB = California Air Resources Board
CEQA = California Environmental Quality Act
CERCLA = Comprehensive Environmental Response, Compensation and Liability Act
CNMPs = Comprehensive Nutrient Management Plans
CP = commercial product
CRIA = Cumulative Risk Index Assessment
CRIS = Current Research Information System
DTFCO = dynamic triangle forced-choice olfactometers
EAC = electrostatic air cleaning
ED_{50} = Effective Dose with 50% panelist detection
ELGs = effluent limitations guidelines
EPCRA = Emergency Planning & Community Right-To-Know Act
EQIP = Environmental Quality Incentive Program (USDA-NRCS)
EU = endotoxin units
FDM = Fugitive Dust Model
FTEs = Full Time Equivalents
GAO = General Accounting Office, U.S. Government
GC-FID = gas chromatography-flame ionization detector
GC/MS = gas chromatography and mass spectrometry
GIS = Geographic Information System

HAP = hazardous air pollutants
IAQ = indoor air quality
ISC3 = Industrial Source Complex/Version 3 Model
LTV = lowest toxic values
MOU = Memorandum of Understanding
MPCA = Minnesota Pollution Control Agency
NAAQS = National Ambient Air Quality Standards
NADP/NTN = National Atmospheric Deposition Program/National Trend Network
NAPAP = National Acid Precipitation Assessment Program
NOV = Notice of Violation
NPDES = National Pollution Discharge Elimination System
NRCS = Natural Resource Conservation Service
OSHA = Occupational Safety and Health
OU = odor units
PPP = pollution prevention plan
RCP = reduced crude protein
RCPF = reduced crude protein fiber
RQ = reportable quantity
SAPRAs = state air pollution regulatory agencies
SIP = State Implementation Plan(s)
SWRCB = State Water Resources Control Board
TAMU= Texas A&M University
TCFA = Texas Cattle Feeders Association
TLV = threshold limit value
TMD = total mood disturbances
TMDLs = Total Maximum Daily Loads
TNRCC = Texas Natural Resource Conservation Commission
TPDES = Texas Pollutant Discharge Elimination System
TSP = total suspended particulate
USDA = United States Department of Agriculture
USDA-ARS = U.S. Department of Agriculture-Agricultural Research Service
USDA-CSREES = U.S. Department of Agriculture-Cooperative State Research, Education, and Extension Service
USDA-NRCS = U.S. Department of Agriculture-Natural Resources Conservation Service
USEPA = United States Environmental Protection Agency
USFWS = U.S. Fish and Wildlife Service
WHO = World Health Organization

2. Chemical Compounds

Al_2 = Aluminum
C = Carbon
$CaCl_2$ = Calcium Chloride
CH_4 = Methane
CO_2 = Carbon dioxide
CP = crude protein
H_2S = Hydrogen sulfide

HCl = Hydrochloric acid
N = Nitrogen
NBPT = N- (n-butyl) thiophosphoric triamide
NH_3 = Ammonia
NH_3-N = Ammonia - nitrogen
NO = Nitrous oxide
NO_2 = Nitrogen oxide
NO_x = Nitrogen oxide compounds
P = Phosphorus
pH = Alkalinity
PM = particulate matter
S = Sulfur
SO_2 = Sulfur dioxide
SO_4 = Sulfate
TN = total nitrogen
VFA = Volatile Fatty Acids
VOCs = volatile organic compounds

3. Units of Measure
bph = bale–per-hour
Btu = British thermal units
DT = dilutions to threshold
OU = Odor units; same as dilutions to threshold
PM_{10} = particulate matter having aerodynamic-equivalent mass median diameter of 10 microns
ppb = parts per billion
ppm = parts per million
$\Phi g/m^3$ = Micrograms per cubic meter
$\Phi g/m^2$/minute = Micrograms per square meter per minute

APPENDIX D

Other Recommended Reading

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Parnell, C. B., Jr. 1984. Air Pollution Control for Agricultural Processing Plants. In: Agriculture and the Environment: An Examination of Critical Issues for Food Policy. (John M. Sweeten and Frank J. Humenik, eds.). American Society of Agricultural Engineers, St. Joseph, MI. pp 107-117.

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Parnell, C. B. Jr., B. W. Shaw, B. Auvermann, and J. McClure. 2000. Engineering of PM_{10} and $PM_{2.5}$ Samplers. Proceedings of the 2000 Beltwide Cotton Production Conferences. National Cotton Council, Memphis, TN.

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Zhang, Z., T. L. Richard, and D. S. Bundy. 1999. Effects of Organic Cover Biofilters on Odors from Liquid Manure Storage. Paper No. 994087, Presented at the ASAE/CSAE International Meeting, Toronto, Ontario, Canada, July 18-21. ASAE, St. Joseph, MI.10 p.

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APPENDIX E

USDA-Agricultural Research Service

- **National Program 203 Air Quality**
- **Air Quality Component/National Program on Manure and By-Product Utilization**

Specific Program Initiatives

Particulates
Understand and assess emissions of primary particulates of 0.1 to 10 micrometer size by agricultural operations, including burning and animal production, and wind erosion. Understand and assess emissions of ammonia, pesticides, and other volatilized organic compounds as precursors to secondary particles by agricultural operations.

Odors
Assess emission of odorous compounds by agriculture, especially those released by animal operations. Understand microorganism-based processes that produce odors, environmental effects on emissions and transport, and impacts. Develop odor-mitigating practices in the context of the entire animal operation.

Impact of Ground-Level Ozone on Agriculture

Understand the bio-physical processes by which ozone causes crop damage and of the interactions between ozone and such other environmental factors as CO2 concentration. Understand ozone impacts on yield and quality and mechanisms of plant response to ozone.

Pesticides and Other Organic Compounds

Assess and understand the processes of emissions of pesticides and other synthetic organic compounds. Quantify the unintentional airborne movement of pesticides from agricultural sites, and determine the impact of agricultural pesticide drift on non-target organisms on and off the farm.

Ammonia and Ammonium Emissions

Improve measuring and monitoring technology and assess ammonia and ammonium emissions under field conditions.

USDA-Agricultural Research Service
Air Quality Component of the
National Program on Manure and By-Product Utilization

Specific Program Thrusts

Develop Methods to Measure and Quantify Emissions from Livestock Facilities

Methods will be developed to accurately measure emissions, e.g. ammonia, particulates, odors, volatile compounds and other greenhouse gases related to livestock facilities. These methods will be based on physical and chemical properties including size and composition of particulates and aerosols and will be reliable and reproducible across a wide range of environments and animal production systems.

Determine Mechanisms Responsible for Emissions

The focus of this research will be to identify the underlying substrates and processes involved in emissions with emphasis on the role of microorganisms. The ecology of aerobic and anaerobic microorganisms associated with emissions will be determined, mechanisms to change the ecology or metabolism of organisms to reduce undesirable emissions will be identified, and methods to promote favorable changes in ecology or metabolism of these organisms will be developed.

Quantify Emission Rates from Livestock Production Systems

Emission rates of gases and particulates will be determined in relation to manure handling, storage, processing, and application practices commonly used in U. S. livestock production systems. Emission will be correlated with management practices to allow identification of best management practices.

Determine Dispersion of Gases and Particulates Across Complex Landscapes

Develop methods to predict dispersion and transport of gases and particulates from animal production and manure application sites. Determine the influence of interactions among emissions (gases, particulates, and aerosols) on atmospheric transport and dispersion.

Develop Cost-Effective Methods to Reduce Problem Emissions

Research will be conducted to determine if current best management practices can reduce emissions to acceptable on-site and off-site levels. Alternative management practices will be developed to reduce emissions and achieve most efficient use of nutrients by animals.