White Paper

Summaries

National Center for Manure and Animal Waste Management

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National Center for
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White Paper Summaries

This document contains summaries of the 20 White Papers that are now being finalized by the National Center for Manure and Animal Waste Management. The White Papers, which are being written to update the state of the science on newly developing priority areas for animal production and waste management, are but one product of the National Center. More information on the Center, which is supported by a four-year USDA Fund for Rural America grant, is available at the Center's Web site, at http://www.cals.ncsu.edu/waste_mgt/natlcenter/center.htm. Information on the complete White Papers will be available on the Web site.

The National Center for Manure and Animal Waste Management consists of 16 universities and a Policy Advisory Committee that are supported for a four-year period under the USDA Cooperative State Research, Education and Extension Service Fund for Rural America Program. Stake holders such as commodity groups, agribusiness, environmental organizations, and state and federal governments are represented on the Policy Advisory Committee.

Center efforts emphasize the development and dissemination of knowledge and technology for sustainable, profitable and internationally competitive animal production that also protect community interests and environmental quality. Working with producers, agribusiness and policy makers, the Center is fusing interdisciplinary research, extension and education activities to produce a holistic understanding of animal waste and manure production and management.

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The National Center White Papers

The purpose of the National Center White Papers is to assess the current state of the science for newly developing issues in the area of manure management. This assessment will serve as the foundation for directing future research and knowledge dissemination activities. There are limitations to this assessment effort.

In some cases, no data are available, data are only available for limited geoclimatic areas of the United States or data are not available for all animal types or types of production units.

White papers may reveal these data deficiencies or identify additional information needs. Moreover, for some issues there may be different interpretations of the meaning or patterns associated with available data or data insufficiencies. Consequently, the White Papers should be viewed as only the first stage of describing the state of the science in these emerging areas of manure management. Continued support for the activities coordinated by the National Center will generate new data to address existing deficiencies and future statements that build on the foundations established by the White Papers.

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Current Status

Odor from Concentrated Animal Feeding Operations (CAFOs)

- ❑ CAFOs affect air quality through emissions of odor, specific odorous gases (odorants), odor-carrying particulates (including organic, inorganic and biological particulate matter), and volatile organic compounds (VOCs).
- ❑ Odor from CAFO sources as experienced by humans is the composite of 170 or more specific gases in trace concentrations.
- ❑ Odorous gases of primary concern often include: hydrogen sulfide (H_2S) and VOCs, including volatile fatty acids.
- ❑ Odor research in the field and laboratory has largely focused on measuring concentrations in terms of dilutions to threshold (odor units per cubic meter) and odor intensity based on category or reference scaling

Emission Characteristics

- ❑ Data on odor/odorant emission rates, flux and emission factors are seriously lacking.
- ❑ Systematic efforts have not yet been initiated to develop accurate emission factors for odorous gases (VOCs, H_2S, etc.) that properly represent CAFOs in the United States. These factors are needed to develop science-based permitting and abatement policies.

Human Response

- ❑ Odor from CAFOs can cause physiological or psychological health responses with regard to (a) frequently exposed neighbors at high concentrations and (b) certain people with particular sensitivities for whom the health effects are of greater concern.

Current Federal and State Policies

❑ Federal and State policies regarding CAFOs primarily have addressed water quality protection from point sources under the federal Clean Water Act and equivalent state statutes; however, only in a few cases have these policies addressed odor and odorants.

Integrated Mitigation Programs

❑ Approaches to control odor and odorants include: ration/diet modification, manure treatment, capture/treatment of emitted gases, and enhanced dispersion. Each of these mitigation approaches includes several specific technologies.

❑ A particular CAFO may require implementation of one, two or more approaches in order to meet the environmental quality demands of the area in which it is located.

Research and Technology Transfer Needs and Opportunities

Odor Measurement and Assessment

❑ Develop accurate standardized measurement technologies for odor and odorants of principal concern and ensure these systems become widely available for research, demonstration and regulatory efforts.

❑ Direct future monitoring efforts toward determining those odorous gases that most closely correlate with odor as perceived by humans.

❑ Develop electronic measurement devices that eventually may be correlated with human perception of odor.

Odor Emissions

❑ Develop accurate and broadly applicable odor/odorant emission rates, flux and emission factors applicable to CAFOs in the United States.

❑ Define odor/odorant emission rates as a function of diurnal, seasonal and climatic variations as well as design and management practices.

Odor Control

❑ Identify kinetic release mechanisms for odorants and odor from principal manure sources and target the development of control technologies accordingly.

❑ Determine relationships among odor, odorants and particulates.

❑ Develop effective, practical and economically feasible odor control technologies for confined animal facilities, manure and wastewater treatment, and land application systems.

❑ Develop innovative air treatment processes for confinement building exhausts and treatment systems (e.g., lagoon surfaces).

Odor Dispersion

❑ Develop accurate dispersion models for odor, odorants and PM appropriate to specific types of CAFOs, addressing the inherent problems of Gaussian models, in order to characterize odor intensities, concentration, frequency and/or duration as a function of distance from CAFOs.

Technology Development and Transfer to Producers

❑ Develop and implement interagency programs of research, education and technical assistance to address odor and other air quality issues from CAFOs.

❑ Develop and deliver effective, reliable and economically viable odor control/mitigation technologies to CAFO producers.

❑ Implement cooperative industry/agency/university programs for practical-scale scientific evaluation of innovative technologies or new products for producers' consideration and adoption.

Odor and Potential Health Concerns

❑ Assess potential relationships between odor, odorants, constituent concentrations, emission flux, emission factors, downwind distribution and potential health indicators and devise appropriate mitigation strategies accordingly.

❑ Identify potential health concerns associated with odor/odorants from CAFOs, and develop suitable acceptability criteria for community-level exposure to odor and specific associated gases.

SITE SELECTION OF ANIMAL OPERATIONS USING AIR QUALITY CRITERIA

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The siting of new animal production facilities and expansion of existing facilities in the United States has become increasingly difficult due to the air quality concerns of residents surrounding livestock and poultry operations. Such concerns often include the effects of nuisance odors on quality of life and the effects of odors and manure gases on both human health and the environment. This white paper primarily addresses the development of setback distances with regard to nuisance odor issues, although some general discussion on human health issues related to emissions from animal production sites is included. Environmental concerns such as water quality impacts and recreational land-use issues stemming from livestock and poultry facility emissions are only mentioned and not fully discussed.

Consolidation of the poultry, beef, swine and, most recently, dairy industries has led to significant changes in animal production. Most animals are now raised in specialized production facilities that are, in the opinion of most animal producers, a vast improvement over traditional housing systems, where animals were exposed to pathogens, parasites and predators and subjected to harsh weather extremes. The transition to intensive rearing of animals has been overwhelmingly positive for the livestock industry: Animal mortality rates have been reduced, feed efficiencies have improved and productivity has increased. However, new problems have arisen for the industry, one of which is the impact of animal-based agriculture on air and water quality, which subsequently affects the siting of animal production operations.

In modern animal housing systems, manure is often removed from the buildings to provide more sanitary growing conditions. This is done either quickly by gravity (through concrete slats) or on a daily or weekly basis by mechanically scraping floors. The liquid manure or slurry removed from buildings is often stored outside in earthen basins, in above-ground storages or in-ground concrete tanks. Slurry may also be stored in concrete pits beneath livestock buildings. Some animal housing systems, particularly poultry buildings, allow solid manure with large amounts of bedding to accumulate on the floors. Any animal facilities, especially those that store either solid or liquid manure inside the building, must be ventilated to remove manure gases, moisture and heat from the indoor air to provide a healthy environment for the animals housed. As a result, odors and gases are inherently released from animal housing during this air exchange.

Manure produced in animal production facilities that is not stored is collected regularly, usually daily, and spread on cropland. However, daily or frequent hauling and application of manure is not an option for most livestock producers due to agronomic considerations, weather conditions or labor concerns. If the animal producers raise crops, there is typically no available cropland on which to spread manure during the growing season, so manure storage is necessary. In a vertically integrated animal production system, private landowners contract with companies to provide land, facilities, utilities and labor in return for a fee to finish the animals (Barker, 2000). These producers no longer grow crops that are directly fed to the animals raised in their buildings, but rather receive formulated feed from the companies' mills. Some animal production systems have become much larger without a corresponding increase in their land base, thus relying on agreements with neighboring crop farmers to apply manure to the neighbor's cropland. If the manure is utilized either on the animal producers' land or someone else's, it typically must be stored for several months before it can be spread. The manure storage units necessary for this storage have become a significant source of odor and gas emissions.

The establishment of setback distances based on airborne emissions from animal production units requires knowledge of federal, state and local concentration or emission standards. The regulation of air emissions requires enabling legislation, rules and regulations, and an enforcement process (Lesikar et al., 1996). Congress passed the original Clean Air Act in 1955 and has subsequently amended the act to regulate air pollution at the federal level. The Environmental Protection Agency (EPA) is directed to interpret the intent of congressional legislation related to environmental matters and to formulate the rules and regulations that implement legislation such as the Clean Air Act. This act established ambient air quality standards for six compounds: nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), lead (Pb) and particulate matter (PM). The PM category was initially for only PM_{10} (particles less than 10 mm in aerodynamic diameter). However, recent concerns about human health effects caused by fine PM (Lippmann et al., 2000) have led the EPA to propose new standards for $PM_{2.5}$ (particles less than 2.5 mm in aerodynamic diameter).

In addition to formulating environmental quality standards, the EPA delegates authority to the states and provides oversight of State Air Pollution Regulatory Agencies (SAPRAs). These agencies must first obtain regulatory authority from their respective state legislatures then formulate rules and regulations in regard to air quality for the state. State air quality standards are often more stringent than the National Ambient Air Quality Standards (NAAQS) set by the EPA and can also include constituents such as odor and gases that are not regulated at the federal level. In reviewing existing state standards for hydrogen sulfide (H_2S), ammonia (NH_3) and odors, we found that 42 of 50 states have standards for one or more of these particular airborne contaminants.

The use of setback distances between livestock and poultry farms and neighboring residences and businesses is the most common method used to reduce the impact of odorous air emissions from animal production sites. Determination of setback distances is difficult and usually involves compromises; large setback distances often restrict the development of new or the expansion of existing animal production sites, while small setback distances are insufficient to mitigate the frequency and severity of nuisance events. The determination of appropriate setback distances is imperative to the viability of the livestock production industry and the quality of life of neighbors. However, many setback distances are determined on the basis of anecdotal and subjective information rather than objective and scientific relationships.

The airborne emissions from animal production sites that should be considered when determining setback distances include odor, gases, dust, insects and microorganisms. The quantity and proportions of these emitted materials are primarily a function of animal species, facility design and management. Odor emissions from animal production sites are probably the most important factor to consider when determining setback or buffer distances from neighbors and communities. Other airborne emissions may have a greater environmental impact, but odor is typically used as an indicator for these other pollutants, and everyone has a sensor for odor.

The establishment or determination of setback distances from animal production facilities can be accomplished using a guideline approach or by the use of dispersion models. Guidelines are used to determine setback distances based on criteria such as parametric formulas based on animal units, animal housing system, physical size of operation or similar parameters. The dispersion model method is a more robust tool that inputs specific airborne emissions such as odor, ammonia or pathogens from the animal production site as well as weather conditions then estimates a concentration of the pollutant (odor, ammonia, etc.) downstream, which can be used to establish a setback distance.

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AIR QUALITY AND EMISSIONS FROM LIVESTOCK AND POULTRY PRODUCTION/WASTE MANAGEMENT SYSTEMS

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This paper summarizes the information available in the literature related to gaseous concentration and emissions of the following constituents from livestock and poultry buildings as well as from manure management systems (storage and treatment units): odor, hydrogen sulfide, ammonia, methane, non-methane volatile organic carbon, dust, microbial and endotoxin aerosols.

Animal agriculture can be a source of numerous airborne contaminants, including gases, odor, dust and microbes. Numerous gaseous compounds and living organisms are generated from livestock and poultry manure decomposition shortly after it is produced, during storage and treatment, and during land application as a fertilizer on cropland. Particulate matter and dust come primarily from both feed and animals. The rate of generation of these gases, microorganisms and particulates varies with weather, time, species, housing, manure handling system, feed type and management system used. Therefore, predicting contaminant presence and concentrations is extremely difficult.

Research in the United States, Europe and elsewhere has shown that some animal production systems have reduced contaminant generation rates as compared to other production systems. Numerous control strategies are being investigated to reduce the generation of airborne materials. However, even when best management systems and/or mitigation techniques are used, airborne contaminants or sub-products are generated. Contaminants may build up concentrations inside livestock and poultry buildings that result in animal and human health concerns. Most of these concerns are associated with chronic or long-term exposure. On the other hand, both human and animal health concerns or safety hazards can result from acute or short-term exposures, like those experienced during agitation and pumping of liquid manure from a pit inside a slatted-floor livestock building.

Once airborne contaminants are generated, they can be emitted from the sources (building, manure storage, manure treatment unit or cropland) through the barn's ventilation system or by natural (weather) forces. Emission rates are dependent on many factors: time of year and day, temperature, humidity, wind speed and other weather conditions, ventilation rates, housing type, manure properties or characteristics, and animal species. Determination of emission rates for gases and odor, dust and microorganisms is an active area of research both in the U.S. and Europe. Emission rates from point sources (buildings) and area sources (manure storage and treatment units and manure applied on cropland) are difficult to determine accurately. There is no standardized collection technique, and there are many uncontrollable factors and conditions that affect measurements. Emission rates of only a few of the many gaseous compounds identified have been investigated. Ammonia and methane are the most common gases studied and measured because of the negative environmental impact they can have on ecological systems. There are very little emission data for other contaminants such as odor, non-methane volatile organic compounds, dust and microorganisms. The environmental and health effects of these ambient air contaminants on people, animals and the environment surrounding animal production sites are only beginning to be investigated. In certain areas some or all of the emission contaminants have created environmental or health concerns, but long-term impacts on ecological systems and people are not known.

HEALTH EFFECTS OF AERIAL EMISSIONS FROM ANIMAL PRODUCTION AND WASTE MANAGEMENT SYSTEMS

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Overview

The rapid proliferation over the last decade of concentrated animal feeding operations (CAFOs) has raised concerns about health effects of aerial emissions from animal production and waste management systems. These aerial emissions are predominantly a mixture of hydrogen sulfide (H_2S), ammonia (NH_3), volatile organic compounds (VOCs) and particulate matter (PM) (including bioaerosols). H_2S, NH_3 and VOCs arise from degradation of waste material. Particulates include manure, dander (hair and skin cells), molds, pollen, grains, insect parts, mineral ash, feathers, endotoxin and feed dust. Recent community studies unrelated to CAFOs suggest that chronic exposure to low levels of H_2S (in the low ppb range) may induce negative health effects. Acute health effects due to H_2S can begin to occur with exposure in the low ppm range. Levels of H_2S in CAFOs tend to range from 500 ppb to 2 ppm but can be much higher if manure is agitated. Consequently, H_2S in animal facilities can pose a risk to workers' health. H_2S levels are diluted downwind, but more research is necessary to determine if ambient (or peak) levels in neighboring communities pose a health risk. Levels of ammonia in animal facilities are often above sensory irritation thresholds and thus can impact workers' respiration. However, ammonia levels tend to be low downwind because ammonia is lighter than air and because it is chemically reactive. The aggregate impact of total VOCs may affect workers and neighbors by inducing strong odors and even sensory irritation. Dust levels within animal facilities can present a health risk to workers, but more research is necessary to determine if ambient (or peak) levels in neighboring communities pose a health risk. Further studies are necessary to quantify the specific levels of components in complex mixtures of pollutants, including H_2S, NH_3, VOCs, PM and odors that induce specific health symptoms. It must be determined if health symptoms are related to time-averaged ambient concentrations or to peak concentrations of single discrete pollutants such as H_2S and NH_3 or to simultaneous exposure to all of the components in the mixture. It is probable that health symptoms are related to the combined effects of multiple components in the emissions.

Hydrogen Sulfide H_2S

Hydrogen sulfide (H_2S) is a colorless, flammable gas that smells like rotten eggs at low concentrations. Because H_2S has a specific gravity heavier than air, it stays close to the ground and can accumulate in enclosed, poorly ventilated, and low-lying areas. The odor detection threshold for H_2S ranges from 0.5 ppb to 30 ppb for 83% of the population, while the irritant threshold ranges from 2.5 to 20 ppm. Thus, the odor threshold for H_2S (as well as other sulfur-containing compounds) is 3-4 orders of magnitude (that is 10^3 and 10^4 times) below the level that causes classical irritant symptoms.

The scientific literature on H_2S suggests that health symptoms can occur with chronic exposure to H_2S concentrations far below the levels at which acute irritation or toxicity occur. Six community investigations near paper mills, refineries, geothermal sources and meat packing plants indicate that exposure over a period of time to low levels of H_2S or other reduced sulfur compounds (below the irritant threshold) can cause health effects. In two of these community studies, health effects were found from an average daily exposure to 10-11 ppb H_2S. These health effects included eye, respiratory or neuropsychological symptoms.

Acute exposure to H_2S at levels in the low ppm range (1 to 7 ppm) can also induce health symptoms including headache, increased airway resistance, coughing, throat irritation and eye pain. At 30 ppm, H_2S becomes neurotoxic and induces nasal lesions in olfactory mucosa. At 200 to 1000 ppm, brief exposure to H_2S can be fatal.

Levels of H_2S inside CAFOs (e.g., 1 to 2 ppm) tend to be above those that have been reported in other settings to elicit health symptoms with chronic (and in some cases acute) exposure. Furthermore, measurements of ambient H_2S downwind of swine facilities can exceed 50 ppb. Fatal cases of H_2S poisoning have occurred in both humans and animals during processing of manure when agitation released toxic levels.

Ammonia

Ammonia is a colorless gas at ambient temperature and pressure. At concentrations above 0.7 ppm, it has a pungent, sharp, repellant and acrid odor. The eye irritation threshold (irritation just barely noticeable) for ammonia is 4 ppm (3 mg/m^3). Decrements in baseline PFT tests (pulmonary function tests) have been reported in workers exposed to NH_3 at concentrations of 7 ppm in tandem with other aerial contaminants. Ammonia is released from the natural decomposition of organic material, including manure as well as dead animals and plants. Ammonia concentrations up to 200 ppm have been found in some animal (e.g., poultry) confinement facilities, but typical levels are much lower (5 to 70 ppm). Comparison of ammonia concentrations measured in animal feeding facilities with human responses to these concentrations suggests that health symptoms (mainly nasal or respiratory irritation) can occur in some of these facilities.

Volatile organic compounds (VOCs)

An overview of studies of VOCs emitted from animal facilities indicates that hundreds of compounds are present. In a recent analysis of VOCs emitted from swine facilities in North Carolina utilizing gas chromatography and mass spectrometry (GC/MS), over 300 compounds were identified. Many more compounds were present, but the GC peaks were too small to allow identification. The compounds identified by GC/MS were diverse and included many acids, alcohols, aldehydes, amides, amines, aromatics, esters, ethers, fixed gases, halogenated hydrocarbons, hydrocarbons, ketones, nitriles, other nitrogen-containing compounds, phenols, sulfur-containing compounds, steroids and other compounds. Acids, phenolic compounds and aldehydes were present in the highest concentrations. The magnitude of total VOCs associated with animal feeding operations and/or waste management systems varies widely from as low as 0.60 mg/m^3 in a recently cleaned swine facility to 108 mg/m^3 from the headspace of a chamber containing slurries produced by weaner pigs. The effect of a large number of VOCs in aggregate is cumulative. Exposure to low concentrations of hundreds of compounds simultaneously can produce high levels of odor and irritation downwind of CAFOs. Introduction of irritant compounds into the upper and/or lower respiratory tract has been found to produce many systemic responses including altered respiration.

Particulate Matter Including Bioaerosols

Epidemiological evidence predominantly from urban settings indicates that exposure to increased levels of particulates is associated with increased mortality risk, especially among the elderly and individuals with preexisting cardiopulmonary diseases, such as chronic obstructive pulmonary disease, pneumonia and chronic heart disease. Epidemiological studies also suggest that particulate exposure can increase the risk of respiratory and cardiovascular morbidity such as increased hospital admissions or emergency room visits for asthma or other respiratory problems, increased incidence of respiratory symptoms or alterations in pulmonary function. This effect can begin to occur when ambient particles <10 microns in size reach a level of 30 to 150 micrograms/m^3, according to the Committee of the Environmental and Occupational Health Assembly of the American Thoracic Society. The concentration of total particles as well as respirable particles (<10 microns) inside confined animal buildings far exceeds the 30 to 150 micrograms/m^3 level at which symptoms can purportedly begin, according to the Committee of the Environmental and Occupational Health Assembly of the American Thoracic Society. Typical total particulate levels inside swine confinement houses are 5 mg/m^3, but levels can reach from 15 mg/m^3 up to 52 mg/m^3 in some houses, with respirable dust comprising 5 to 50% of the total dust.

Odor

All of the emissions described above can induce odor sensations. Health complaints associated with odorous emissions from animal facilities include eye, nose and throat irritation, headache, nausea, diarrhea, hoarseness, sore throat, cough, chest tightness, nasal congestion, heart palpitations, shortness of breath, stress, drowsiness and alterations in mood. These symptoms typically occur at the time of exposure and remit after a short period of time. Health symptoms may persist for longer periods of time as well as aggravate existing medical conditions in sensitive individuals such as asthmatic patients. A report from a recent workshop (co-sponsored by Duke University, the Environmental Protection Agency and National Institute on Deafness and Other Communication Disorders) on our current state of knowledge regarding the health effects of ambient odors from animal operations concluded that malodorous emissions can negatively impact health.

PARTICULATE MATTER EMISSIONS FROM CONFINED ANIMAL FEEDING OPERATIONS: MANAGEMENT AND CONTROL MEASURES

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Objectives

- ❑ Summarize the state of knowledge concerning the sources, emissions and control of particulate matter from Confined Animal Feeding Operations (CAFOs).
- ❑ Guide producers in the selection of appropriate facility designs, manure handling and other approaches to mitigate the effects of particulate matter emissions from CAFOs.
- ❑ Identify key gaps in the research base concerning PM emissions from CAFOs.

Introduction

Particulate matter (PM) is among the most prominent air pollutants associated with confined animal production. In general, PM consists of solid- or liquid-phase particles whose settling velocity in air is too small to overcome the changing aerodynamic forces exerted upon them by normal air currents. Particles may be emitted directly by a source (e.g., hoof action on uncompacted, dry manure), or they may be formed in the atmosphere (known as secondary PM) as a result of chemical reactions involving one or more precursor gases, including ammonia (NH_3). Once emitted or resuspended into the air, PM may eventually settle out or be intercepted by obstructions or surfaces, but its general tendency is to remain suspended in air well beyond what its trajectory would be in a vacuum. Health-based standards for airborne PM exist for both occupational and ambient conditions.

Control Techniques

Control of PM from CAFOs depends on the housing configuration (open lot vs. enclosed) and the type of PM being considered (primary vs. secondary PM). For open-lot CAFOs, increasing the frequency with which manure is harvested will control PM emissions by reducing the depth of dry, uncompacted manure subject to hoof action. PM emissions can be controlled to an arbitrary extent by the application of supplemental moisture via solid-set sprinklers, towed "big gun" sprinklers or water trucks; the extent of control is related to the frequency and depth of water application. Frequent manure harvesting to minimize the depth of dry, loose manure will increase the effectiveness of supplemental water applied for dust control. Increasing the stocking density (number of animals per unit area) increases the moisture excreted per unit area of open-lot surface, but this strategy appears to control PM emissions only modestly in semi-arid regions and may give rise to unacceptable feed-to-gain performance losses associated with increased agonistic behavior. Surface mulches, modified feeding schedules and topical application of salts and resins are all experimental control methods. For livestock and poultry produced under roof, PM emissions may be controlled by misting with water or various oils (e.g., soybean oil). For swine production over slatted floors, increased stocking density will reduce PM emissions by increasing the hoof action that pushes manure accumulations into the pits or flush gutters below rather than leaving it on the surface to dry and to be resuspended. The length and orientation of feed delivery tubes may be adjusted to reduce PM emissions from feed boxes. To the extent that secondary PM results from CAFO ammonia emissions, the control of ammonia emissions will help to reduce the stoichiometric potential for fine-particle formation. Ammonia emissions are covered in more detail in a companion paper (Arogo et al., 2001). Emissions of PM from unpaved roads can be controlled by consistent application of supplemental water or holding pond effluent, by periodic application of petroleum-based resins, or by restricting vehicle ground speed.

Major Research Gaps

1. Open-lot CAFOs

PM emissions from open-lot CAFOs have received limited research attention but are becoming a higher priority in semi-arid regions of the United States. Most of the research thus far has focused on the use of supplemental moisture to increase manure compaction and reduce dust potential. Other approaches require greater attention, particularly in regions where supplemental water is scarce. Emission factors for PM from open lots are variable and inaccurate, and dispersion models for ground-level area sources need to be improved.

- ❑ Document and/or refine NH_3 emissions estimates from open lots in relation to feed composition, stocking rate and regional/seasonal hydrology.
- ❑ Using direct, physically based methods, generate new emission factors for open-lot PM that are not artifacts of Gaussian or other empirical dispersion models.
- ❑ Quantify the emissions reductions and normalized costs of open-lot abatement measures such as increased stocking density, active water application, mulches and manure harvesting practices.
- ❑ Quantify the effect of source-boundary controls such as vegetative barriers and “water curtains” on downwind PM concentrations.
- ❑ Determine the influence of diurnal moisture applications and other control measures on the profile, viability and persistence of bioaerosols in open-lot PM emissions.

2. Livestock and poultry housing

Much more data need to be taken on emission rates in order to better determine both mean emission rates and variability of emission rates due to various environmental and management factors. Such factors as litter moisture, feed characteristics and lighting management all have effects on dust generation, and it will require a number of studies in order to confidently recommend management procedures to improve dust emissions. Dust control technologies need further analysis. While air ionization is promising, much work needs to be done in order to see if this technology can be applied economically, reliably, and safely. Other dust reduction technologies are also in their infancy and need to be developed further in order to test their economic and environmental viability.

3. Secondary fine particles (ammonium salts)

Research should address standard methodology to adequately quantify ammonia emissions, particularly in open housing and various climates and climatic conditions that promote the formation of PM. Once emissions can be quantified in a reasonably reliable fashion, then it is possible to evaluate management practices thought to reduce emissions. Research must address multi-media impacts of all manure collection, handling, treatment, storage and utilization options commonly employed by livestock producers.

In short, little is known about the direct impact of CAFO-derived ammonia on regional enrichment of fine PM. Research needs in this regard are fundamental.

- ❑ Quantify the contribution of CAFO-derived ammonia to regional or airshed-scale enrichment of fine PM.
- ❑ Validate dispersion models that incorporate algorithms for formation of secondary PM from volume and area sources of ammonia gas.

4. Monitoring and dispersion modeling

- ❑ Develop and validate dispersion models that account for differential settling velocities across the full distribution of particle sizes in CAFO-derived PM.
- ❑ Improve and validate deposition algorithms for CAFO-derived PM.
- ❑ Impress upon the research community the critical need to provide averaging times along with monitoring and/or sampling data.
- ❑ Improve the design of size-fractionating ambient PM samplers for applications to agricultural PM.

AMMONIA EMISSIONS FROM ANIMAL FEEDING OPERATIONS

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The purpose of this paper is to summarize the state of knowledge regarding ammonia (NH_3) emissions from animal feeding operations. Based on the information in published literature, the paper summarizes:

- ❑ The effects of NH_3 emitted from animal production to the environment;
- ❑ Emission rates and quantities from animal buildings, storage and treatment facilities, and land application sites;
- ❑ Ammonia emission measurement methods;
- ❑ Models for NH_3 emissions, transport and deposition; and
- ❑ Possible control strategies and technologies.

Atmospheric NH_3 is produced by the decomposition of organic materials, biomass burning and fertilizer production and utilization. Ammonia is involved in plant metabolism and can be exchanged between vegetation and the atmosphere. Ammonia emissions abatement has had high environmental priority in parts of Europe in recent years, and it is receiving more attention in the United States as a potential air and water quality concern. The primary concerns about ammonia emissions into the atmosphere are: (1) nutrient deposition in nutrient sensitive ecosystems and (2) formation of aerosol particles that may cause haze and impair visibility and are also a concern for potential health effects from respirable particulate matter.

Agricultural activities, livestock production in particular, have been reported to be the largest contributor of NH_3 emissions into the atmosphere. Farm animals consume a considerable amount of protein and other nitrogen (N) containing substances with their feed. The conversion of dietary N to animal product is relatively inefficient, and 50 to 80% of the N consumed is excreted. Ammonia is produced as a consequence of bacterial activity involving the excreted organic N substrates.

Ammonia can be emitted from animal housing, manure storage and treatment facilities, and manure land application in animal production operations. Factors that affect NH_3 volatilization include source characteristics (manure, building type, storage and treatment methods, and land application method), pH, temperature, wind speed, and surface characteristics. At this time, the majority of data for emissions from animal feeding operations are from Europe, where buildings, manure management and climate are often different than in the U.S. Previously, little research on ammonia emissions has occurred in the U.S., but research is increasing. Progress is being made in development of measurement equipment and methods, but the expense of measurement and lack of continuous measurement capability has hindered the development of reliable annual emission factors. Typically, data are collected over short durations, and extrapolations beyond the sampling periods and conditions are prone to error.

Emission rates are usually expressed in terms of mass of NH_3 or ammonia nitrogen (NH_3-N) per unit time and per animal (or live weight units) or per unit area (surface sources). Although air quality literature uses units of NH_3 mass in reporting emission data, this paper uses NH_3-N mass because it simplifies its use in N accounting for confined animal production. To convert NH_3-N mass to NH_3 mass, multiply by 1.214.

The ranges of measured emission rates can be large among the European and U.S. data. Building emissions range from 0.2 to 5, 0.12 to 1.48, 0.28 to 0.74, and 0.5 to 10 g NH_3-N/h-AU (1 AU=500 kg live weight) for pigs, dairy cattle, beef cattle and poultry, respectively. Storage/treatment losses reported are 0.25 to 156 and 3 to 90 kg NH_3-N/ha-day for lagoons and storage tanks, respectively. Land application losses range from 14 to 83%, 6 to 47%, and 0 to 7% of total NH_3-N applied for surface spread, band spread and injected manure, respectively. Data on NH_3 emission measurements from beef cattle feedlots and large dairies with open housing in the U.S. are limited. The NH_3 losses from the various sources at animal production operations are often expressed in different units or on different basis, making it more difficult to calculate NH_3 loss per animal. Some of the reported emissions are derived from direct assumptions that a certain percentage of N excreted by the animal is lost due to NH_3 volatilization. Without measurements, these assumed emissions should be used with extreme caution. Additionally, N excretion data for all animal species need better documentation. Published information indicates ±30% variation, and it is even complicated further with the current efforts in dietary manipulation to reduce N excretion.

Ammonia emission rates from different sources in animal feeding operations have been used to develop emission factors. The ammonia emission factor for animals in an animal production operation represents the sum of the annual mean emission rates from housing, manure storage/treatment and land application. Emissions factors are based on average annual conditions and typically a composite of various animal sizes and types for a particular animal species. Emission factors currently used in the U.S. are based on those developed for Europe. Composite emission factors in Europe are 14.8 to 23.5, 2.3 to 5.2 and 0.20 to 0.23 kg NH_3-N/yr-animal for dairy, swine and poultry, respectively. The corresponding emission factors estimated for the U.S. based mainly on European data are 18.7 to 18.9, 4.7 to 6.0 and 0.18 to 0.24 kg NH_3-N/yr-animal for dairy, swine and poultry, respectively. Emission factors need further determination, especially for livestock and poultry production in the U.S. Also, use of a composite emission factor should be discouraged and emission factors for different production management systems and subsets of animal species (e.g., for pigs: sows/piglets, growing pigs, gestating sows, boars, etc.) should be developed and used instead. This would allow more accurate determination of ammonia emission for specific animal feeding operations. Another deficiency with the emission factors is that they are usually developed from measurements taken over short periods of time, during which the weather, operating conditions and animal sizes and numbers may not represent the annual average conditions. This leads to under or over estimation of ammonia emission factors when the value obtained during the short period of measurement is extrapolated annually. Thus, it is important to develop reliable and accurate measurement methods and to develop the capability to monitor continuously for long periods if accurate annual emission factors are to be determined. Also, increased emphasis on changing diets to reduce N excretion and other management changes to reduce ammonia emission have the potential to significantly change NH_3 emissions. This makes it necessary to reevaluate the emission factors developed earlier to incorporate changing trends in animal production operations.

Measurements of NH_3 concentration and flux provide a basis for formulating emission factors for the different sources at an animal production facility. They are necessary for estimating inputs for models and determining the effects of management changes for controlling emissions. Measurement methods currently used include chemiluminescence analyzers, denuders, detector tubes, optical absorption techniques, wet chemistry and gas chromatography. Ammonia fluxes are estimated using N mass balance, micrometeorological, chamber and wind tunnel, and tracer gas methods. Comparisons of various methods for measuring NH_3 fluxes can yield differences of greater than 200%. Agreement within 20-30% for different methods is generally considered good. Lack of a proven "ground-truth" method makes it difficult to calculate absolute errors. Mass balance on N should be considered with every measurement as a check on reasonability of NH_3 emission measurements, even though it may be difficult to determine the fate of all the N that is consumed by an animal.

Models are important for predicting emissions for different situations and the effects of changes of the factors that affect NH_3 emissions. Some empirical and mechanistic models have been published for NH_3 emission in buildings and from storage/treatment facilities and land application. Most of the empirical models use statistics to obtain correlations and relationships between factors that affect NH_3 emission. Mechanistic models are built based on the emission processes for the NH_3 source and NH_3 transfer to the atmosphere. Transport and deposition models usually are based on Gaussian dispersion. However, the errors of the models are usually difficult to determine.

Reducing NH_3 loss from an animal feeding operation requires a whole farm systems approach, which shows how intervening in one aspect of the farm may affect NH_3 losses in other parts of the operation. Strategies for reducing NH_3 losses should be directed towards reducing: (1) NH_3 formation, (2) NH_3 loss immediately after it has been formed, or (3) the NH_3 loss potential. Some of the control practices that are potentially useful for reducing NH_3 loss from animal production facilities are summarized in Table 1.

TABLE 1. Potentially useful ammonia control practices for animal production.

	Source or Location			
	Excreted Manure and Urine	**Confinement Facilities**	**Treatment & Storage**	**Land Application**
Control Practice	Reduce N excreted by reduced protein diets or improved balance of amino acids Dietary electrolyte balance affecting urinary PH	Minimize emitting surface area Remove manure frequently (belt transport, scrape and/or flush) Filter exhaust air (bioscrubbers, biofilters or chemical scrubbers) Manure amendments (acidifying compounds, organic materials- enzymes and biological additives)	Cover to reduce emissions or collect gas NH_3 stripping, absorption and recovery Chemical precipitation (e.g., struvite) Biological nitrification (aerobic treatment) Acidifying manure	Injection or incorporation into soil soon after application Application method to reduce exposure to air (e.g., low-pressure irrigation near surface, drag or trail hoses) Acidifying manure

Research Needs and Issues

Until recent years, most concern for ammonia lost from manure was because of the influence on reducing fertilizer value. Some of the previous research on N losses during storage, treatment and land application was also useful for determining overall ammonia losses to the atmosphere. However, much additional research is needed to specifically address ammonia losses from animal feeding operations and the nature and extent of environmental and health effects resulting from ammonia emissions. Specific research needs are:

- ❑ Determination of environmental impacts of NH_3 deposition on land, crops and water;
- ❑ Determination of on-farm and off-farm health effects of NH_3;
- ❑ Evaluation and standardization of NH_3 concentration measurement methods and NH_3 emission or flux methods;
- ❑ Improved determination of emission factors for various animal types and sizes and for various animal and manure management facilities and practices;
- ❑ Improvement and validation of models for NH_3 emission, transport and deposition;
- ❑ Evaluation of the effectiveness of technologies and control strategies; and
- ❑ Economic evaluation of control strategies.

LAND APPLICATION OF MANURE FOR BENEFICIAL REUSE

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The concentration of animal production systems has increased efficiency and improved overall economic return for animal producers. This concentration, along with the advent of commercial fertilizers, has led to a change in the way animal producers view manure. Manure, once valued as a resource by farmers, is now treated as a waste. Air and water quality concerns that arise primarily from the under-utilization or inefficient use of manure contribute to these changing views. However, when properly used, manure is a resource and should be regulated as such. In the United States, the *USDA/EPA Unified National Strategy for Animal Feeding Operations* outlines how animal feeding operations should be regulated and acknowledges that land application at proper agronomic rates is the preferred use for manures. However, many limitations such as water quality concerns, uncertainty regarding manure nutrient availability, high transportation costs and odor concerns cause some to question land application. This paper documents the benefits of land application of manure, discusses limitations that hinder greater manure utilization and outlines research and extension needs for improving manure utilization.

Manure is an excellent source of major plant nutrients such as nitrogen, phosphorus and potassium and the secondary nutrients that plants require. Plant nutrients in commercial fertilizers are mostly water soluble and readily available for plant uptake, while the nutrients in manure are less available. This complicates the determination of application rates, but the slower release contributes to improved plant utilization and decreased nutrient losses to surface and groundwater. Many studies have demonstrated that crop yields on land application areas are equivalent or superior to those attainable with inorganic fertilizers. Crop quality has also been improved by manure additions. These improved responses are usually attributed to manure-supplied nutrients or improved soil conditions not provided by inorganic fertilizer. Manure, especially poultry litter, can also neutralize soil acidity and raise soil pH. This liming effect can further increase the value of manure.

Research has shown manure application can have a significant impact on the chemical, physical and biological properties of the soil. Most of these effects are due to an increase in soil organic matter resulting from manure application. The ability of manure to promote formation of water-stable aggregates in the soil has a profound effect on soil structure and physical characteristics. Water-stable aggregates increase infiltration, porosity and water holding capacity and decrease soil compaction and erosion. Through improvement in soil physical properties, manure application also reduces the energy required for tillage and the impedance to seedling emergence and root penetration. Soil organic matter is known to affect a number of soil chemical properties, such as the cation exchange capacity and the soil buffering capacity that enable manure-treated soils to retain nutrients and other chemicals for longer periods of time. Soil organic matter is known to affect activity, degradation and persistence of pesticides, and several studies have shown reduced pesticide losses from manure-treated fields.

The land application of manure can affect soil erosion and surface water runoff. Several laboratory and rainfall simulator studies on manure-amended soils indicate runoff and erosion rates are influenced by manure characteristics, loading rates, incorporation and the time between application and the first rainfall. The broad range of research objectives, underlying assumptions, manure types and environmental conditions create differing results. Field plots established to collect runoff from natural precipitation events consistently indicate that manure can substantially reduce both runoff and soil erosion when solid manures are land applied. Results using lagoon effluent or slurries are less conclusive. Nevertheless, this is a substantial benefit that should be considered when determining the water quality impacts of land application.

Land application of animal manures can help mitigate potentially negative consequences of rising atmospheric CO_2 on the global climate by contributing to greater sequestration of carbon in soil. In general, soil organic carbon sequestration on an area basis appears to be greater with an increased rate of manure application. Climate appears to affect potential retention of applied carbon in soil, with warmer regions tending to have lower carbon retention rates from manure (7±5%) than temperate or frigid regions (23±15%). Methane is also a significant contributor to global warming, and animal agriculture is a significant contributor of methane emissions globally. Land application of manure can significantly decrease the net quantity of methane emitted to the atmosphere compared with stockpiling or long-term lagoon storage of manure.

The benefits of utilizing manure through land application are apparent. However, there are several impediments that discourage greater use of manure nutrients in cropping systems. These include potential water quality problems associated with runoff, uncertainty associated with the nutrient availability, high transportation and handling costs that discourage transport and greater utilization, and public perception regarding odor issues.

Potential pollutants of concern in livestock wastes are organic materials, nutrients and pathogenic microorganisms. Surface water is primarily affected through soluble contaminants in runoff or insoluble pollutants carried on soil particles during soil erosion events. Groundwater can be contaminated with excessive pollutants from percolation, seepage and direct infiltration. Nutrients are the most common pollutant associated with animal waste. Several studies have documented that watersheds with predominantly animal agriculture tend to have higher nutrient levels in their drainage systems. Over-application of manure to crops or grasses can result in leaching of nitrate to groundwater or high levels of nitrogen in surface waters, resulting in eutrophication and low dissolved oxygen levels. Research has shown that the concentration of phosphorus in runoff increases as the phosphorus concentration in the topsoil increases. Manure presents a special problem because the nitrogen-to-phosphorus ratio in manures is lower than that needed by crops. As a result of the low nitrogen-to-phosphorus ratio in manure, excess phosphorus builds up to environmentally harmful levels in fields that receive repeated applications. Compared to nitrogen and phosphorus, much less research has been done on bacteria and other pathogens in manures and their impact on water quality.

The primary way to reduce the risks associated with land application of manure involves addressing the application rate, timing and location. These issues are commonly addressed through nutrient management planning. The *USDA/EPA Unified National Strategy for Animal Feeding Operations* establishes a national performance expectation that all Animal Feeding Operations should develop and implement technically sound, economically feasible Comprehensive Nutrient Management Plans (CNMPs). Traditionally, nutrient management has involved optimizing the economic return from nutrients used for crop production. Today the agronomic and economic requirements of nutrient management remain central, but the process is being expanded to include the potential environmental impacts of nutrients on the entire farm operation. This increases both the cost and complexity of these plans, yet few studies have documented the effectiveness of nutrient management plans, and some studies suggest it is difficult for farmers to reduce environmental impacts even with well-developed plans. Often nutrient management plans do result in benefits for farmers and society, especially as an educational process; however, implementation has not been as great as desired.

Even under ideal conditions, there is still a significant risk of losses to the environment. Agricultural systems leak, and elimination of non-point source impacts is practically impossible. Therefore, secondary treatment or preventive systems should also be incorporated into the design of all land application systems, regardless of the choice of nutrient source. There are a number of best management practices (BMPs) that can be adopted to reduce the water quality impact of land-applied manure. The method and timing of manure application can be adjusted to reduce the amounts of constituents transported in runoff. Practices that limit soil erosion or runoff will positively impact surface water quality, while practices that reduce leaching should help prevent groundwater contamination. Conservation tillage, contouring and strip cropping, terraces and vegetated waterways have all been used effectively to minimize runoff. Narrow grass hedges have also been employed to reduce runoff, control erosion, decrease nutrient transport and provide wildlife habitat. Secondary treatment systems such as vegetative buffer zones, grass filter strips, riparian zones and/or other vegetative filters can prevent nutrient and pathogen movement to surface waters. Containment systems like ponds and diversions may also be used. Ultimately, the goal of these systems should not be treatment but should be a secondary system that ensures that contaminated runoff does not directly enter surface water. The need for these types of systems is highly dependent on the receiving water body, as often these secondary systems are not economically justified. Studies addressing the cost-benefit and efficiency of these systems on the farm and comprehensive watershed scale are needed to aid in producer decisions and help with water quality modeling efforts. Educational programs and policies to inform and to encourage adoption of current conservation technologies and BMPs by farmers are also an immediate need.

Farmers often choose to use commercial sources of fertilizers instead of manure because of variability and uncertainty concerning manure nutrient availability. Although estimates of nutritional content can be obtained through published literature, due to the variability in farming practices, animal diets, climate and waste storage facilities, manure nutrient analysis is usually recommended. Currently, most farmers sample their manure regularly but wait extended periods for test results. The development of inexpensive, on-farm nutrient tests would allow for testing at the time of application and more frequent and dependable test results. Obtaining representative manure samples presents unique challenges depending on the physical nature of the manure involved. In the case of wet manure, one of the main sampling challenges is to obtain a representative sample from manure slurry that has different liquid and solid phases.

Where animal production is concentrated, the land base available for manure application is usually limited. This limitation arises from restrictions imposed by the economics of manure transportation. The transport, collection, intermediate storage and general handling of manure to and from the point of processing or use are and will continue to be problems. Little research emphasis is being placed on the concepts of materials handling and metering for animal manure, yet the economics of transporting the material to the point of use is often the greatest concern limiting livestock producers from maximizing the use of this biomass resource. The export of manure from surplus to deficit areas for use as a fertilizer is often economically viable at larger scales. However, large-scale transfers of manure are not occurring, suggesting a need for increases in the incentives given to commercial firms to provide manure brokering. Better integration of farms that produce crops and livestock, and educational programs aimed at showing farmers the economic value of manure as a fertilizer are other methods of reducing the transport costs. Separation, screening, condensing and dewatering technologies could also be used to produce more transportable products; however, little research is being conducted in these areas.

Public perception of agriculture in general and land application in particular is critical to continued acceptance of manure application as the primary utilization strategy. Public concerns with animal manures can be broken into three major categories: water quality, air quality and food quality. Land application of manures has the potential to negatively impact all three. Improved technical information should be communicated to the general public about environmental, social and political concerns and potential solutions.

MANURE MANAGEMENT STRATEGIES/TECHNOLOGIES

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A number of manure management strategies are used for both open lot and confinement facilities in the United States. The primary control strategies for open lots are solids removal using settling basins and containment followed by land application of the liquids. These management strategies are dictated by federal law for large open lots. Smaller lots may or may not capture and land apply the runoff liquid. Both large and small lot operators must haul and distribute manure solids on the land. The development of solid manure spreaders that apply uniform rates is a major research need.

Confinement facilities rely primarily, but not exclusively, on liquid handling systems.

Two general categories of liquid systems are pits, or slurry systems, and lagoons, primarily anaerobic lagoons. Anaerobic lagoon design has been researched and is well known to environmental engineers. Anaerobic lagoons work better in warm climates where biological activity continues most of the year. Anaerobic digesters with controlled temperatures can be used to produce biogas and reduce pathogens but are difficult to justify due to high capital costs, high management requirements and a lack of incentives for using the systems. Covered lagoons and anaerobic digesters can significantly reduce odors and releases of unwanted gases.

Naturally aerobic lagoons can reduce nitrogen in the liquid significantly, but are impractical because of large size requirements. Mechanically aerated lagoons are sometimes used. Autothermal thermophilic aerobic digestion, biofilm reactors, sequencing batch reactors and combinations of anoxic and aerobic treatments are being researched and offer advantages of odor reduction and waste degradation and stabilization. Additional research is needed to optimize these systems for nutrient reduction, pathogen destruction and energy use.

Solid-liquid separation can be used for both open lots and confinements. Open lots typically use settling basins. Confinements typically use mechanical separators. The efficiency of a separator depends on the type of waste and the separator. It’s difficult to achieve high efficiencies of separation without pretreatment with coagulating chemicals. Solids from both separators and from open lots are sometimes composted.

Wetland treatment of manure liquids has received some research attention. It has been shown to offer some nutrient reduction advantages when designed properly. Initial design parameters have been determined for animal waste systems, but continued research is needed to adapt wetland systems to different types of livestock operations.

Chemical amendments remain a question. Both feed additives and manure additives have been tested by a number of researchers and have achieved only moderate success at best. Much research is needed before chemical additives will be major contributors to manure control solutions.

Land application systems are well developed but always need continued work to improve efficiencies and effectiveness. One of the primary areas of research needs currently is for injection units that minimize disturbance of the soil and crop residue cover.

Insect digestion of manure solids has been well researched in laboratory settings. Effective field production systems need to be devised, and uses for the resultant high protein feedstuffs need to be developed.

Many of the above technologies can be combined into integrated treatment systems that protect soil, air and water quality.

TREATMENT LAGOONS FOR ANIMAL AGRICULTURE

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The term "lagoon" is often misused. Farmers, the press and the public tend to call all earthen manure storage basins lagoons. The title lagoon, however, has a specific meaning. ASAE standards define a lagoon as "a waste treatment impoundment…(in which manure) is mixed with sufficient water to provide a high degree of dilution…for the primary purpose…(of reducing) pollution potential through biological activity. Treatment lagoons are not drawn below their treatment volume…except for maintenance."

Many of the problems associated with liquid manure handling systems — liner seepage, accidental overflows, catastrophic embankment failure, pathogen release, odor emissions and closure of earthen basins — are not unique to lagoon-based systems. These problems are shared by all liquid systems. Other white papers in this series touch upon these issues. The emphasis of this white paper is the biological treatment potential of lagoons.

Lagoons rely on physical, chemical and biological processes to degrade manure. Biological processes play the greatest role in degradation. Growth and maintenance of biological communities depend on temperature, food, the absence of toxic elements and the ability of organisms to remain in the lagoon long enough to reproduce.

Microbiological communities are vertically segregated in lagoons. Each layer performs a separate function in the overall treatment process. Photosynthetic organisms play a major role in the degradation of sulfur and nitrogen-containing compounds as well as odoriferous elements; therefore, the presence of the proper wavelengths of light to perform photosynthesis is also important in lagoon biology.

Lagoons function best when operated as flow-through systems with a mechanism to periodically remove effluent. The most common method of effluent removal is to recycle plant nutrients through irrigation to crops. Local patterns of rainfall and evaporation (and the amount of rain produced by isolated storm events) determine whether a lagoon has a net surplus of effluent or whether water must be added to the system to maintain material flow through the lagoon.

Two challenges must be addressed if lagoons are to remain a viable treatment alternative for animal agriculture. They are:

1. Inefficient recovery of plant nutrients;

2. Odor and ammonia emissions.

Up to 80% of all nitrogen entering lagoons cannot be accounted for in lagoon effluent, and a great portion of manure phosphorus entering lagoons is retained in sludge. Plant nutrients are less concentrated in lagoon effluent than in other manure treatment products, although lagoon effluent has a better balance of nitrogen to soluble phosphorus than most sources of manure nutrients. Lagoon effluent should be used in crop production on a nitrogen basis, irrigating effluent in multiple applications throughout the growing season. Managing effluent in this manner requires expensive, permanent irrigation equipment to apply what is essentially low-quality fertilizer. Nitrogen application is inherently out of sync with phosphorus since the majority of manure phosphorus is only recovered when solids are removed at the end of the sludge storage cycle, which may last as long as 10 to 20 years.

Large chemical compounds are transformed into smaller, more volatile compounds through biological degradation. These small compounds may be less odorous than those found in raw manure, but their volatility makes them more likely to be emitted into the atmosphere. Ammonia gas is produced during anaerobic degradation of proteins and urea. A portion of the ammonia created in lagoons is undoubtedly lost through atmospheric emission. Recent studies suggest that much of the atmospheric release of nitrogen may be in the form of harmless N_2 gas, however.

Lagoons located in temperate climates undergo annual cycles of storage, heating and organic matter accumulation. Cool season organic matter accumulation is most pronounced in extreme latitudes. The heating and organic matter accumulation cycles are problematic in that there is a tendency for lagoon layers to become unstable in the spring and fall, increasing the likelihood of odor emissions during these periods.

Mass of atmospheric emissions increases with lagoon size, and many of the problems of liquid manure handling — liner seepage, the consequences of catastrophic failures, wave erosion — are exacerbated by lagoon size. Current anaerobic lagoon design standards rely on volumetric organic loading rate to size the treatment volume. This means that lagoon size is directly proportional to farm size. A second consequence of relying on volumetric loading rate as the sole design parameter is that lagoon geometry cannot be changed without altering other potentially important design parameters, such as depth and surface area to volume ratio.

This paper does not specify a maximum size for lagoons nor does it advocate abandoning volumetric loading rate as a design parameter. Pretreatment to reduce the mass of organic matter entering lagoons is suggested as a method to limit lagoon size on larger farms. Improvements in lagoon performance will be realized when specific biological communities, prescribed to perform specific treatment steps, are engineered to be present in individual lagoon cells or layers. Design refinements are needed to reach this point. Research should focus on filling the following information gaps.

1. Achieve a greater understanding of the fundamental biological processes involved in manure degradation.

2. Achieve a greater understanding of the chemical transformations involved in lagoon treatment.

3. Achieve a greater understanding of the physical and climatic factors that lead to cyclic environmental conditions experienced by lagoon microorganisms in temperate climates.

4. Develop diagnostic tools capable of monitoring biological communities in natural environments.

5. Develop design parameters to promote specific, robust biological communities in lagoons, given a set of environmental conditions and influent characteristics.

Educational materials must be produced to train operators to maintain lagoons. These materials should be sensitive to the operator’s need to work within the limitations of an agricultural production system. Curriculum should include:

1. Basic treatment biology;

2. The cyclic nature of lagoon operation;

3. Liquid balance to maintain proper lagoon operating levels;

4. Operating within an actual water year, not an average year;

5. Efficient nutrient use;

6. Maintaining structural integrity.

THE PHOSPHORUS INDEX: BACKGROUND AND STATUS

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Introduction

Resource managers are struggling with developing and implementing equitable programs that will minimize phosphorus (P) loss to our nation's waters. One of the most promising management tools for accomplishing this difficult task is the P Index, a tool designed for use by resource managers to assess and rank fields as to their relative P loss potential. While the intent and fundamental framework of the P Index remain the same, many versions of the P Index exist and are in varying stages of evolution due to differing regional and geographic conditions. The purpose of this document is to provide a brief review and update of the present status of the P Index, using examples where possible, and to demonstrate the evolving nature of this complex process.

Current Iterations: Northeast Region Leadership

Transport and Source Factor Separation. Since the inception, several changes have occurred regarding the mechanics of calculating the P Index. One of the most fundamental changes is the separation of the factors affecting P loss into those directly affecting P transport (erosion, runoff, leaching, etc.) and those directly affecting the P source (soil test P, P application rate and method, etc.).

Multiplicative vs. Additive Calculation. To better represent actual site vulnerability to P loss, source and transport factors are related in a multiplicative rather than additive fashion. For example, if surface runoff does not occur, site vulnerability should be low regardless of soil P content. By contrast, in the original version, a site could be ranked as highly vulnerable even though no surface runoff or erosion occurred. However, some caution is advised for cases of catastrophic events that occur infrequently yet can greatly increase the amount of transport from a site. On the other hand, a site with a high potential for runoff, erosion or leaching but with low soil P is less at risk for P loss unless P as fertilizer or manure is applied.

Base Two vs. Linear Transport Factor Calculations. In the original version of the P Index, transport factors were assigned ratings of VL, L, M, H and VH using a base 2, (i.e., 0, 1, 2, 4, 8, and 16.) Since no scientific basis for using the base 2 approach was provided, current P index versions used in several Northeastern states have altered calculations to include the use of a linear approach (tons/acre or pounds/acre x factor), especially for those parameters such as erosion, whose impact could also be considered linear.

Transport Factors Normalized $(E+R+\ldots/3X_{E+R+\ldots})$. Recognizing the importance of the transport factor, the Northeastern states have developed a mechanism for normalization. This is accomplished by adding each transport factor rating ($E + R + \ldots$) and dividing by the sum of the potential maximum of individual transport factors ($3X_{E+R+\ldots}$). The resultant quotient is then multiplied by the P source factor.

Distance or Proximity to Stream, Channel Connection, and Return Period. Designers of the initial and evolving versions of the index appreciate the importance of incorporating a mechanism that defines the geographic location of the field to the water body of concern. Therefore, a qualitative estimate is needed of the likelihood that direct runoff from a field will reach the water body in question. Inclusion of this concept receives broad support from index designers, but unfortunately, it is difficult to define. Some states simply use the distance to a stream (Maryland and Delaware), while others try to take into consideration channel topography (Nebraska).

Leaching and Surface Drainage. The extent of P transport to the surface waters via solute movement through the vadose zone can be significant but differs in degree due to variation in local conditions. For example, it has been demonstrated to be an important transport mechanism in Maryland and Delaware, where regions of course-textured soils, high water tables and excessive soil P levels overlap. Where appropriate, some P Indexes address this concern by including a leaching and surface drainage component as part of the transport factor.

P Sensitivity or Watershed Priority. The P sensitivity of the surface water into which the field drains is clearly a critical factor in assessing the significance of whether or not P loss from the field is important. Incorporating the concept into a P Index in a workable manner is another matter. Some versions have included P sensitivity or priority of the watershed as a factor in the P Index (Maryland and Delaware). For example, USDA-NRCS policy requires that an assessment of P movement be performed if the watershed has been identified as P sensitive or if manure is applied to the field. Alternatively, the user could consider P sensitivity as a pre-condition for running the index.

Best Management Practices (BMPs). Effectiveness of BMPs in reducing P loss is well accepted, and a consensus exists as to their importance in the index. Some index architects suggest there should be a third component (transport, source and BMPs), while others design their efficiency into existing factors. For example, buffer width (Vermont) and P application methods (Pennsylvania and Vermont) are recognized as important aspects of the transport and source factors, respectively. Others recognize the role of feed and manure additives in altering the solubility of manure P or simply reducing P loss.

Other Iterations

P Index for Pastures. Another innovative program with broad geographic application is the P Index for pastures, which is multiplicative, with four terms: P Index for pastures = (P Source) * (P Transport) * (BMPs) * (Rainfall). Rather than use a relative scale such as 1-100, the P Index for pastures estimates P load in pounds acre^{-1} year^{-1}.

Fields are assigned a P Index of low, medium, high or very high if the estimated P load is <0.6, 0.6-1.2, 1.2-1.8, and >1.8 pounds acre^{-1} year^{-1}, respectively. When the value is low or medium, manure application can be based on nitrogen. When values reach the high or very high level, applications are based on P removal and no manure application, respectively.

P Index for Cropland. The Iowa P Index emphasizes estimating P delivery from cropland by incorporating characteristic elements common to most indexes, current research data, survey results and scientific judgement where data is lacking. Source and transport characteristics are considered in a multiplicative manner in three components to yield an overall relative risk index. The Erosion Component considers sheet and rill erosion (RUSLE), sediment delivery (based on modified watershed-level sediment delivery ratios and sediment trap factors), sediment P enrichment for various tillage and ground cover combinations, soil-test P, total soil P and vegetative buffers. The Runoff Component considers water runoff (modified runoff curve numbers), soil-test P, and rate, time and method of P application. An Internal Drainage Component considers the presence of tiles, an index of water flow through the soil profile, soil-test P, and rates of P application through their effect on soil-test P.

Others. While the Northeast Region remains one of the most active in modifying the P Index, other regions have been developing indexes suitable to their climate and geography. For example, because of the arid or semiarid climate of the Western region of the United States, P Indexes in these states reflect a low transport potential. Washington and Oregon are using the same set of P Indexes, but one P Index is used in the drier Western portions of these states and another is used in the wetter Eastern areas. Most of the Midwestern states are taking a more traditional approach with the P Index, while Iowa's approach is more process oriented and designed to predict annual P loads. In addition to the common P Index parameters for identifying P loss potential via soil erosion and runoff, P export via field tile effluent can be a significant transport pathway in some Midwestern soils, and this loss mechanism is being included where appropriate.

Summary and Conclusions

As intended in the original design, the P Index will continue to evolve and reflect regional and local conditions. While subjective aspects of the index will remain, investigators are encouraged to field test their index and continue to seek the necessary interdisciplinary and multi-agency participation. Also, because the area is evolving so rapidly, the architects of the respective P Indexes are encouraged to reexamine their particular P Index to ensure that their version encompasses the latest concepts and technology. While the details of the indexes may differ from region to region, some consistency regarding approach appears to be evolving. The separation of the transport and source factors and normalization of the transport factor (0-1) and index scale (0-100) are examples. While the importance of the transport factor is recognized, adequately depicting the values in a quantitative way is proving most difficult. Resource managers and decision makers need practical screening tools to efficiently implement the P Index. More user-friendly software packages are also needed for automatic parameter input and computation of the index.

MANIPULATION OF ANIMAL DIETS TO AFFECT MANURE PRODUCTION, COMPOSITION AND ODORS: STATE OF THE SCIENCE

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The amount and composition of freshly excreted manure can vary considerably and is primarily influenced by the original composition of the diet. In addition, feeding management practices can influence the efficiency of nutrient utilization in livestock and poultry operations. Odorous and gaseous compounds are emitted after excretion due to microbial metabolism in the digestive tract of the animal. Since the animal is the initial source of nutrient excretions and odors from animal operations, diet manipulation is a practical and potentially economical way to control excess nutrient excretions and odor emissions that will have a major impact to minimize pollution of water, soil and air. Research related to using diet manipulation to reduce nutrient excretions and minimize odors from livestock and poultry is summarized.

Optimizing nutrient availability and proportion in the diet to meet the animal's maintenance and production requirements is a recognized practice to decrease nutrient excretion. For instance, N utilization can be enhanced in cattle when they are fed degradable and undegradable protein in the correct balance. Similarly, in poultry and swine, the most optimal way to reduce N in excreta is to lower the amount of crude protein (CP) fed and to supplement diets with synthetic amino acids (AA). Reducing excess N from protein and balancing the essential profile required by the animal can substantially increase the efficacy of overall N retention in the animal. In swine, the impact of AA supplementation with low CP diets to reduce N excretion ranged from 28 to 62% depending upon the size of the pig, level of dietary CP reduction and initial CP level in the control diet. The average reduction in N excretion per unit of dietary CP reduction was 8.4%. Recent studies verified that practical swine diets with low CP and synthetic AA could reduce N excretion and ammonia emissions from 30 to 55%, hydrogen sulfide emissions by 30% and olfactometry odor measurements by 30%. However, on a practical basis, broiler chicken performance can be hindered by these lower CP diets due to a number of factors: reduced K levels, altered ionic balance, lack of nonessential AA, imbalances among and/or potential toxic concentrations of certain AA. There has been little research with turkeys, ducks and layers focusing on the reduction of CP and the addition of synthetic AA with the aim of reducing N excretion. With ever-changing genetics within individual animal species, requirements for individual genetic lines and yield-types are relatively uncertain, and research is needed to determine these requirements under commercial situations.

Recent research has reported that use of lower CP diets and phase feeding can reduce N excretion from 12 to 21% in feedlot cattle. This also reduced the runoff of N from the feedlots and reduced the amount of N volatilization losses from the feedlot surface by 15 to 33%. Other technologies that affect nutrient excretion from dairy cows are the use of somatotropin and three-time milking per day compared to two times per day. Improving nutrient utilization in dairy cattle through multiple feed management strategies could reduce N output from 15 to 30% without harming production. Complex carbohydrates such as B-glucans, oligosaccharides and other non-starch polysaccharides (NSP) in animal diets can influence N excretion, resulting in increased bacterial protein production, and affect the electrolyte balance of the diet that will reduce the pH of manure and ammonia emission. This reduced emission of NH_3 is due to changing the ratio of N excretion in urine as urea and shifting the N excretion in feces in the form of bacterial protein. The removal of fiber and germ from corn in swine diets has recently been reported to result in a 56% reduction in dry matter excreted and 39% reduction in N excretion.

Supplementation of P to beef cattle fed in CAFOs is not necessary. Dietary P from typical energy, protein and fibrous feeds is adequate to meet cattle requirements for growth. For years, mineral P supplements have been added to dairy cow diets, typically containing 25 to 40% more P than recommended. The most obvious way to reduce the environmental threat from P in cattle manure is to eliminate excess P in the diet. Currently, it is very difficult to formulate low P diets for cattle by selecting low P containing ingredients. In addition, unfortunately, many by-product feeds used in the cattle industries are fed to reduce feed costs but are high in P. Recent beef cattle research has shown that P excretion can be reduced by 20 to 30% by not adding supplemental P to the diet in group-feeding studies and from 40 to 50% in nutrient balance studies. The reduction of supplemental P in dairy diets can potentially reduce P excretion from 25 to 50%.

The availability of P in the major feed ingredients (corn and soybean meal) for swine and poultry is very low because much of the P is bound to a phytate molecule. Poultry and swine do not have the natural-occurring enzyme phytase in their digestive systems to release the phytic P for productive uses. Therefore, it has been a common practice to add supplemental P sources to the diet, which means a significant amount of P is excreted in manure. New plant genotypes are being developed that contain lower levels of phytate P, such as the new high available P (HAP) corn and soybeans, that provide more available P in the diet for poultry and swine. Consequently, much less supplemental P is added to the diet and much less P is excreted (20-30%). Another management approach is to add the enzyme phytase to the diet to release the phytic P. Considerable recent research has shown that phytase addition will reduce P excretion from 25 to 35%. In addition, the efficacy of using phytase and HAP corn and soybeans together can reduce P excretion 50% and potentially more. Additional enzyme "cocktails," organic acids and vitamin D_3 metabolites can also affect the absorption and utilization of P that will reduce P excretion from 15 to 25%. Since there is considerable variability in the biological availability of P in various feed ingredients, research to determine availability is important for accurate feed formulation. These different availabilities vary due to soil mineral variation, growing conditions, cultivars and other factors. In general, dietary enzyme addition can improve the nutrient availability of feedstuffs and reduce excretion. Data for the P requirements of the broilers, turkeys, layers and ducks of current genetic strains are very limited. Using phase feeding programs to more nearly meet the needs of animals at different stages of the life cycle could significantly reduce P excretion.

Use of organic forms of Cu, Fe, Mn and Zn in swine diets resulted in lower levels of these minerals being added to the diet and excreted compared to conventional dietary mineral sources. Reduced dietary Cu, Zn, Mn and Fe concentrations fed throughout the life cycle of swine for three parities did not depress growth or alter feed efficiency and enzymatic activities indicative of health parameters. Salt and potassium (K) concentrations in the diet are critical in semi-arid and arid climates, where salinity problems can exist and sodium accumulation can adversely affect crop production. High salt levels will limit feed intake; however, this increases salt excretion. Potassium accumulation in forages receiving manure application with excessive K levels can potentially cause grass tetany conditions with cattle consuming forages with these high K levels. Minimal research has been conducted on the effects of diet on odor emissions from cattle manure, and this may become a major issue for cattle production in the future.

Research Needs

- ❑ Determine the effects and optimal concentrations of dietary CP levels, forms, ratios, AA levels, ratios and their interactions on animal performance, manure N composition and atmospheric N loss.
- ❑ Determine N requirements under varying production settings, production levels and stages of the animal life cycle. Quantify N excretions and forms at each stage of life cycle. Determine the available AA requirements of major genetic lines of animals under defined environmental and commercial conditions.
- ❑ Develop strategies to increase the retention of N for the production of milk, eggs and lean tissue. Develop metabolism modulators to increase retention of N and lean growth.
- ❑ Determine available P requirements of animals and excretion outputs of P on various diets.
- ❑ Develop nutritional strategies that improve the utilization of feed P and reduce P excretion, including phase feeding programs.
- ❑ Determine phytase interaction with vitamins, organic acids, Ca:P ratio, bioavailability of sources, probiotics, etc. on P utilization.
- ❑ Develop feeding strategies that reduce odors and ammonia emissions from manure.
- ❑ Determine the effect of nutrient availability in by-products, genetically enhanced crops and diet processing on nutrient excretion.
- ❑ Conduct mass balance studies to develop models for nutrient retention, excretion and characterization of manure.
- ❑ Evaluate methods to alter acid-base balance of diets for odor control and change in forms of nutrient excretion.
- ❑ Evaluate mineral sources and strategies on nutrient excretion
- ❑ Establish real-time nutrient evaluation of feed sources.
- ❑ Implement new technologies to reduce nutrient excretion on production operations.

In all species, there is a need for accurate manure volume and nutrient data under practical conditions at different ages and diets to assist in the development of storage facilities and comprehensive nutrient management plans (CNMP). Practical field studies to implement and fine-tune diet strategies and technologies are necessary, and in all of these studies, the economic feasibility, environmental benefits and costs of new diet modifications need to be determined. Economics is still a major issue determining if these technologies will be adopted.

CLOSURE OF EARTHEN MANURE STRUCTURES (INCLUDING BASINS, HOLDING PONDS AND LAGOONS)

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Abstract. This paper summarizes what is known scientifically about the closure of earthen manure structures without artificial liners, including lagoons, storage basins and runoff holding ponds, and identifies needs to be examined further to better under the dynamics of closing such structures in an environmentally safe manner. The information presented here should be useful as a guide for state regulatory agencies considering rules for closure and for academicians and consultants who work with livestock production facilities.
Keywords. Lagoons, manure storage, earthen storages, seepage, closure, groundwater contamination.

Introduction

When a livestock production unit ceases operation, proper procedures need to be undertaken to properly close earthen manure structures without artificial liners, including lagoons, storage basins and runoff holding ponds, in order to assure protection of surface and groundwater. There are three primary environmental risks associated with such earthen structures: nutrients and pathogens, which can be a concern for both surface and groundwater quality, and degradable organic matter, which is a concern for surface water due to runoff from structure overflow during the closure process or from land application of the contents.

Earthen manure structures, properly designed, installed and operated according to accepted engineering standards (such as those defined by USDA-NRCS *Agricultural Waste Management Field Handbook* and ASAE Standard EP393.2, "Manure Storage," and ANSI/ASAE EP403.2, "Design of Anaerobic Lagoons for Animal Waste Management," should pose little risk to water quality. A well maintained earthen structure should show:

- ❑ Limited erosion of sidewalls due to wave action;
- ❑ Lack of erosion in the vicinity of a manure inlet pipe;
- ❑ Lack of erosion near areas used for contents agitation and removal;
- ❑ Well maintained sod on berms and exterior sidewalls (weed and tree growth controlled);
- ❑ No signs of burrowing animals in or around the berms or sidewalls; and
- ❑ Lack of seepage around pipes through the sidewall and along the toe of the berm.

The addition of manure to an earthen structure further reduces seepage rates due to physical, chemical and biological processes that contribute to the clogging of soil pores. The NRCS *Animal Waste Management Field Handbook (1992)* acknowledges a reduction in the coefficient of permeability by a factor of at least 10. This suggests that for a properly designed and constructed facility, maintaining an intact structure and liner after abandonment should be an environmentally sound practice to protect against seepage. However this may or may not be considered environmentally sound for other reasons, e.g., if the structure is allowed to overflow.

Poorly designed or poorly constructed earthen liners, as well as badly eroded ones can allow significant movement of contaminants into the soil adjacent to or below the structure before the time of closure. Soil borings may be necessary to accurately assess the movement of nutrients below inadequate earthen structures at the time of closure and to determine the proper procedures necessary for closure.

This paper is a summary of a White Paper prepared for the National Center for Animal Waste National Center for Animal Waste. The purpose of the White Paper was to examine what is known scientifically about closing earthen manure structures without artificial liners (such as lagoons, storage basins, runoff holding ponds) and determine what needs to be examined further to increase our understanding of the dynamics of closing them in an environmentally safe manner. This summary will first provide the authors' general recommendations for closure and then review the methods available for removing the contents of the structure and discuss in more detail the options for closure or alternative uses of the site.

Closure Procedures

General Recommendations

Based on a review of available literature and the professional judgment of the authors, several fundamental principles should be applied to the abandonment of earthen manure structures without artificial liners that were reasonably well designed and constructed and properly maintained during their useful life.

The preparation of an earthen manure structure for closure involves three critical principles:

1) Protection during the closure process of the soil/organic matter interface layer that forms a relatively impermeable natural liner around the structure contents.

2) Removal of all liquids and pumpable slurry.

3) Land application of removed liquids and sludge at agronomic rates.

After liquids and sludge are removed and utilized in an environmentally sound manner, there are four generally acceptable options for completing the closure process. Producers should check with local and state regulatory agencies since the closure of earthen manure structures is sometimes governed by specific state or local regulations. In some states, the producer is required to complete a closure report. Generally acceptable options for closure of an earthen manure storage include the following options.

Option A: Permanent elimination of an earthen manure structure

Option B: Permanent conversion to a fresh water pond

Option C: Breaching of the berm

Option D: Managing earthen manure structures at temporarily depopulated operations

The procedures outlined here assume that the liner has been adequately protected from erosion and other threats to liner integrity. If these assumptions are not correct, soil borings are needed to determine if a more extensive cleanup is required. Regardless of the intended end use, all conveyances (pipes and ditches) used to convey manure to the basin should be removed and replaced with compacted soil. A more complete explanation of each of these principles is given later in this paper.

Solids Characteristics of Typical Earthen Lagoon

In a manure storage or basin, the contents are likely to be relatively uniform throughout, with solids content ranging from 2 to 10%. In an anaerobic lagoon, however, three different zones are likely to be found. These zones seldom have distinct boundaries and are difficult to determine.

1. Relatively inert solids accumulate near the manure inflow points. This material may be high in phosphorus, with a discernible interface between the solids and the sludge. Complete removal of these solids is difficult without damaging the liner. Therefore, maintaining liner integrity should be of even greater concern than removal of all solids. There is typically more solids buildup in lagoons receiving manure from poultry and dairy operations than from swine.

2. A thick sludge, high in nutrients, bacteria and organic matter, is normally located just above the solids zone. Pumps designed to handle high

solids content can remove this material. While much of the readily degradable organic matter in the sludge should be broken down, it is still biologically very active and a likely source of much of the anaerobic degradation of incoming manure occurring in a lagoon.

3. Above the sludge is a liquid layer that is low in solids and moderately rich in nutrients. It is easy to pump with conventional chopper-agitators or irrigation pumps. The liquid and most of the sludge can be removed by pumping while maintaining the integrity of the liner. The liquid can be irrigated onto cropland, but it may be necessary in some cases to move sludge using tanker wagons.

The settled solids and sludge layers of an anaerobic lagoon can contain a significant amount of phosphorus that has settled out over the years (Table 1). According to Barker (1996), organic nitrogen compounds tend to accumulate in the sludge at levels that are up to 13 times higher than in the liquid while phosphorus accumulates at rates that are up to 55 times higher. In addition, the sludge may also contain significant concentrations of heavy metals, salts and other trace elements. These factors dictate the need for laboratory analysis and for expert agronomic advice prior to land application. Sheffield (2000) found sludge volumes and total nutrients to be highly variable in a study of 30 single-cell swine lagoons in North Carolina. He concluded that volume and concentration could not be estimated accurately based on values from other lagoons. Likewise, the land area needed to apply the sludge at agronomic rates was highly variable.

Sludge sampling

Sheffield, et al. (2000) states that measuring and sampling sludge should be done from a boat. For safety reasons, at least three people should be present: two in the boat and one on the lagoon bank. The extra person on the boat assists with entering and exiting the boat, and the extra person(s) on shore may be needed as a rescuer should anything go awry. Flat-bottom boats are recommended over canoes or V-bottom boats. Everyone in the boat should wear appropriate flotation devices.

Sheffield, et al. (2000) recommends measuring the amount of sludge and solids in a lagoon by lowering a lightweight, rigid, 1.27 to 2.54 cm diameter (0.5 – 1 inch) wooden or capped aluminum pole slowly into the lagoon until the liquid seems to become denser and thicker. Record the water level on the pole and continue to push the pole down until you feel you have reached the bottom of the lagoon. Again, record the water level on the rod and remove it from the lagoon. The difference between the readings is the depth of the sludge and solids. Commercially available sludge samplers are useful for collecting samples but do not work well for estimating sludge volume because of the density of anaerobic lagoon sludge. The sludge layer in a lagoon is a mobile fluid that forms peaks and valleys within the lagoon. Sheffield, et al. (2000) recommends that at least 10 depth measurements be taken randomly. For a more detailed assessment of sludge volume, a formal grid should be established over the surface of the structure. The Environmental Protection Agency recommends at least four grids per cell with no grids larger than 930 cu m (10,000 sq ft). Plot depth measurements at grid points to develop a contour map of sludge deposits on the bottom of the storage to estimate the amount of sludge and solids beneath the liquid.

Sheffield, et al. (2000) also states that the best time to take a sludge sample is while measuring for volume of sludge in a lagoon. This allows samples to be collected from several points around the interior of the lagoon. Depending on density and nutrient concentration, the samples may differ by as much as 100 percent from point to point. To draw a sample, insert a 1.3 to 1.9 cm diameter (0.5 to 0.75 inch) PVC pipe into the lagoon sludge until the pipe reaches the bottom. Wearing plastic or latex gloves, cap the end of the pipe to create a vacuum and slowly withdraw it from the lagoon. This will capture a core or profile of lagoon effluent and sludge. Once the pipe outlet is over a clean container, slowly break the vacuum and allow it to drain. Place several samples in the container and mix thoroughly. Use a plastic, wide-mouth bottle and follow laboratory instructions when shipping samples for analysis.

Protecting the Integrity of the Existing Earthen Liner During Closure

No matter which closure method is chosen, maintaining an intact liner is likely less of a danger to the environment than attempting its removal. As much sludge and solids should be removed from the basin as can be accomplished without endangering the integrity of the liner. In the event of poor liner design, construction or management or where the liner has been damaged, nitrogen movement may be found in soil borings beneath the storage. In these cases, removal of several inches of the soil liner may be necessary. However, this should be the exception rather than the rule, and a knowledgeable consultant should determine the need for such measures after soil borings and inspection.

Removal of Liquids, Pumpable Sludge and Solids

Removing sludge and solids from earthen manure structures can be accomplished by several methods.

- ❑ Agitate and remove the combined contents of the structure and land-apply.
- ❑ Remove and land-apply liquids; agitate, remove and land-apply sludge.
- ❑ Remove and land-apply liquids; dredge and land-apply sludge.
- ❑ Agitate and remove the structure contents, concentrate and remove solids, and land-apply.
- ❑ Use a sludge dredge and land-apply without dewatering.

Agitate the Combined Contents of the Structure and Land-Apply

In this method, liquid and sludge are mixed with an agitator or a chopper-agitator impeller pump. High-volume pumps (11,500 to 19,000 liters per minute; 3,000 to 5,000 gallons per minute) specifically designed for agitation and loading provide for suspension of solids. However, agitation equipment is generally only effective in suspending solids within about 15 m (50 feet) of the agitator. Because agitation equipment can erode earthen liners near the agitator, it should be used cautiously. Direct the agitation flow away from the liner and keep the agitation unit at least 3 feet away from the soil surface. The mixed contents can be pumped through a large-bore sprinkler irrigation system onto nearby cropland. At many sites, the removed material should be soil-incorporated to minimize odor, nitrogen volatilization and runoff potential.

Remove and Land-Apply Liquids; Agitate, Remove and Land-Apply Sludge

The liquid portion of the earthen structure is dewatered by irrigation onto nearby cropland or forage-land. The remaining sludge is then agitated and pumped into a sludge applicator. The sludge can be spread onto cropland or forage land or soil-incorporated. This method may not work as well with dairy manure due to its fibrous nature, larger particle sizes and higher solids contents, compared to swine and poultry manure structures. After the liquid and most of the sludge is removed, depending on the condition of the liner, it may be necessary to remove any remaining solids with a small track-type dozer or farm tractor with a bucket.

Remove and Land-Apply Liquids, Dredge and Land-Apply Sludge

The earthen structure is dewatered by irrigation onto nearby cropland or forage land. Sludge is then removed with a dragline or sludge dredge. Note that the dragline must be used very cautiously to avoid damage to the organic liner. With more fibrous manure, it may be practical to establish a gently sloping bermed area beside the structure to receive the dredged sludge and allow liquids to drain back into the earthen structure to provide additional dewatering. This may not be feasible with swine or other non-fibrous sludge that does not stack well. After air-drying to produce a semisolid or solid material, the sludge is hauled and spread with solid manure equipment onto cropland or forage-land at agronomic rates. Soil-incorporation should be used where feasible to better retain and utilize the nutrients in the sludge.

When removing sludge, the pumper or dragline operator must pay close attention to protect the organic liner. Any damage may not be noticeable until the liquid level drops. If the soil liner is disturbed, stop the activity immediately and do not continue until operations are modified to prevent further damage. A damaged liner should be repaired with suitable soil material as soon as possible.

Agitate and Remove the Structure Contents, Concentrate and Remove Solids, and Land-apply

The entire contents of the manure structure is thoroughly agitated and removed. Solids are separated from the mixture of sludge and liquid and the liquid is land-applied. The solids are land-applied, composted or otherwise utilized.

Use a Sludge Dredge and Land-Apply without Dewatering

Pumping dredges are commonly used to remove solids from municipal and industrial wastewater lagoons and holding ponds. A pumping dredge is typically a floating barge with a variable-depth-pumping head to remove sludge from the bottom of the structure. Power units can either be located on the barge or may be hydraulically operated pumping heads with power units located on the berm.

A higher concentration of solids can be removed from a lagoon with the sludge dredge because sludge is removed without agitation or dilution, thus reducing transportation cost. With the assistance of guide cables, dredges work back and forth across a lagoon, working their way down the earthen structure, until the solids are removed. Since the dredges do not use aggressive agitation or cleaning nozzles, equipment manufacturers and operators claim that pumping dredges do not negatively impact the condition of earthen liners.

Pumping dredges are best suited for large structures or where large amounts of solids must be removed. Because of their size and weight, dredges may be placed into and removed from an earthen structure with a crane.

Sludge Reduction Alternatives

Chastain and Darby (2000) studied a thickening process for lowering the cost of removing sludge from a dairy lagoon. By settling sludge from mixtures of sludge and water (1.93 and 3.99% total solids) for seven hours and draining the supernatant back to the lagoon, the volume of sludge was reduced by an average of 60%.

Several companies offer various lagoon additives intended to reduce the volume of sludge in anaerobic lagoons. These products provide a mix of various microorganisms, enzymes, proteins or catalysts to stimulate the microbial degradation of accumulated sludge. The Animal and Poultry Waste Management Center at North Carolina State University has evaluated several of these products since 1997. To date, these studies have been unable to verify significant reductions in sludge volume. This may be due to differences in dosage of product, method of application or type of operation where the products were tested.

Anecdotal information from producers in the Midwest, however, continues to indicate that some of these products may be effective. Some producers have used baker's yeast effectively to suspend solids by spreading 120 gm/l of fresh baker's yeast mixed (1 lb/gal) of lukewarm water at a rate of one l per 1.84 sq m (1 gal/75 sq ft) of liquid surface with the storage agitated and pumped two weeks later. (Sheffield et al., 2000)

Estimated Cost of Liquid and Sludge Removal

The cost of closing an earthen manure structure is a concern for many confined feeding operations. In many cases, the operation is closing because of financial difficulties, and there are simply no funds remaining to properly close the manure structures. Some states have handled this issue at the time the storage is initially approved by requiring a bond to be posted to cover all or part of closure costs. According to the Environmental Review Commission of the North Carolina General Assembly (2000), Oklahoma, Iowa and Missouri already have legal mechanisms in place to ensure that owners have the funding available for lagoon closure and have legislation that holds producers responsible for closing facilities through one-time fees, annual fees and financial sureties (statement of assets, irrevocable letter of credit, cash or cashier's check).

In 2000, the North Carolina Department of Environment and Natural Resources (DENR) reported there were 1,142 inactive lagoons on 745 farms and that 39 were considered high risk. They assigned 93% of the inactive lagoons a medium risk (requiring further study) because of the uncertainty over the behavior of nutrients contained in inactive lagoons and limited data regarding groundwater levels and surface water contamination. The primary source of pollutants in inactive lagoons was assumed to be the sludge because of high N and P levels. Using NRCS standards for lagoon closure, DENR estimated the cost of closure at $105,000/hectare ($42,000/acre), or $30,000,000 to close all inactive lagoons in the state. Actual closure costs in North Carolina were between $1.32 and $8.47 per cu m ($5 and $32 per 1,000 gal) of waste removed, according to the Environmental Review Commission of the North Carolina General Assembly (2000). The estimated closure costs for a 3,785 cu m (1,000,000 gallons) lagoon would thus range from $5,000 to $32,000. This is high enough that producers cannot be expected to voluntarily close their inactive lagoons.

Lindemann et al. (1985) studied sludge removal from three dairy lagoons. A tractor-PTO propeller agitator, a two-stage portable solids handling and irrigation pump worked well to remove high-solids sludge from both dairy and poultry lagoons. The nutrient value of the sludge was sufficient to offset 30 to 50% of the cost of pumping.

Hiring a custom applicator is often a feasible method of managing sludge. The high cost of sludge removal equipment is prohibitive for most producers, especially due to the infrequency of sludge removal. Also, many lagoons can accumulate sludge for up to 10 years or more before their treatment ability declines. The cost of hiring a contractor is largely based on the amount of sludge to be removed. A 1999 survey of custom applicators in Eastern North Carolina (Sheffield et al., 2000) showed that prices ranged from 0.4 to 1.3 cents per liter of sludge (1.5 - 5.0 cents/gal) of sludge. The difference in cost depended on the size of lagoon to be pumped; lagoon accessibility; distance to available application sites and whether the sludge was to be irrigated, broadcast or injected.

Land Application of Liquid and Sludge at Agronomic Rates

Material removed from the bottom of the storage will have significant quantities of nutrients. Producers should obtain a nutrient analysis, estimate the proper application rate based on soil tests and crops to be grown on the application site, and monitor the actual application rate. The accumulation of phosphorus in the sludge commonly determines the minimum land requirement, based on agronomic needs of crops. For this reason, nutrient management plans should consider that all P added to the structure is available for land application eventually and not underestimate life cycle land area requirements.

Factors influencing land area required to apply sludge during closure are:

❑ Nutrient analysis of sludge;

❑ Nutrient analysis of supernatant;

❑ Crop to be grown;

❑ Soil type;

❑ Soil fertility level (phosphorus);

❑ Local/State regulations;

❑ Application method.

Land application rates should not exceed the annual crop nitrogen requirements (land grant university extension services or local NRCS offices can provide assistance in determining recommended land application rates). Application sites should be evaluated for their current soil phosphorus level and risk of runoff or erosion contaminating surface water. State regulations and best management practices must be followed in selecting suitable land application sites.

Specific Earthen Manure Storage Closure Procedures

Option A. Permanent Elimination of Earthen Storage Structure

Option B. Permanent Conversion to a Fresh Water Pond

Option C. Breaching the Berm

Option D. Managing Manure Storages at Temporarily Depopulated Operations

Incremental Closure Procedures

Incremental closure is a modification of Option A listed above. It has been used to close abandoned lagoons in the Southeastern U.S. Incremental closure is well suited for the permanent elimination of lagoons in the following situations.

- ❑ Large surface areas (greater than 2 acres) where agitation is difficult
- ❑ Earthen manure structures with narrow embankments that are unable to support tractors and agitators to suspend settled solids and sludge
- ❑ Earthen manure structures with degraded embankments or slopes
- ❑ Earthen manure structures with bottoms below groundwater table
- ❑ Large length to width ratios that are difficult to properly mix or access with agitator
- ❑ Soil or fill material unavailable locally to completely fill existing structure
- ❑ Earthen manure structures that will ultimately have their sidewalls removed and the facility filled in with soil or reshaped to match the existing contour

An earthen manure structure that is incrementally closed would generally undergo the following steps.

1. Agitation equipment is located at one end or corner of the structure. Sludge is agitated, removed from the structure and land applied.
2. Once the depth of settled/accumulated material is reduced to less than about 0.3 m (1 ft) by agitation and pumping or with a sludge dredge, bulldozers or other earth moving equipment slowly move the sidewalls by adding fill at a rate of approximately 3 to 4.5 m (10–15 ft) at a time toward the center of the structure.
3. As the embankment is pushed inward, the agitated sludge will be displaced by the fill and pushed toward the center of the structure, rather than being covered with soil.
4. Soil cores should be taken to monitor the process and ensure that the fill encloses a minimal amount of sludge. Borings, with a soil auger, should be made and the depth of sludge remaining in the structure after the previous movement of the lagoon embankment estimated. No chemical analysis is required. Rather, the soil cores serve as a quality control practice to ensure that the sludge is being moved toward the open portion of the lagoon, rather than being buried. Cores should be taken along the filled-in area to depths corresponding to the previous bottom elevation of the structure. Each core should represent approximately 70 sq m (750 sq ft) of area. A record should be kept of where the cores were taken as well as a measure of amount of sludge remaining.
5. Agitation equipment is moved across fill surface as the earthen structure is filled in. Agitation, solids removal, embankment movement and soil core samples continue until the structure is reduced to a size manageable by agitation equipment alone or until all contents are removed.

The goal of incremental closure is to remove the vast majority of sludge material while avoiding handling thick layers of sludge greater than 0.13 m (5 inches) and potentially damaging the liner. To minimize the sludge layer thickness while closing the unit:

- ❑ Agitate sludge and solid material periodically, as the structure is closed;

- ❑ Move embankment a shorter distance; or
- ❑ Place the bulldozer blade lower in the existing soil to push sludge material over from beneath.

Timing of Closure

The proper timing of earthen lagoon or manure storage structure closure continues to be debated. Should it be closed immediately upon cessation of operation or would it be better to wait 3 to 5 years? While environmental concerns remain after operation ceases, the level of risk tends to decrease over time if the structure is properly maintained. A number of advantages and disadvantages, both economically and environmentally, exist for either scenario. Allowing more time for closure gives more flexibility in applying the sludge. Applying at agronomic rates may be very difficult given the high concentration of nutrients in the sludge layer, and applying the sludge over a period of years instead of all at once may be more environmentally friendly. The structure must be maintained during this time of disuse just as it was during operation, including regular inspections, controlling burrowing animals, maintaining proper vegetation on berms, and pumping when necessary to maintain safe water levels. Continued maintenance, along with the potential increased cost for setting up equipment to pump sludge multiple times rather than all at once, may represent a significant cost to the operation.

Advantages of immediate closure include:

- ❑ Expense of maintaining berms and pumping lagoon ends quickly;
- ❑ Possibility of overtopping or leakage ends quickly;
- ❑ Closing it in one operation should minimize expense of pumping and hauling sludge.

Advantages of slower closure include:

- ❑ Pathogens existing in sludge are more likely to die or be reduced to insignificant levels;
- ❑ Nutrients in sludge can be applied at agronomic rates over a longer period of time;
- ❑ Nutrients in sludge can be applied at agronomic rates over a longer period of time.

Summary and Conclusions

A thorough review of the literature dealing with closure of animal manure lagoons and earthen manure storages shows quite varied results and indicates the need for a site-specific evaluation in order to accurately evaluate the potential environmental damage from closure. Still, there are several conclusions that can be reached.

The overall potential for environmental contamination should be taken into account when closing a structure. Application on land with crops that can utilize the nutrients without damage to ground or surface water must be available. It may be important to properly schedule the removal and land application of sludge over a period of several crop years to ensure this happens. If land is not available to apply the sludge, other means of utilization must be available.

A site-specific evaluation is important to ensure that the structure was properly sited, designed, constructed and operated. If it was not and if an investigation shows contamination of the site is ongoing, closure procedures should be completed as soon as possible.

There are a number of questions that remain after our literature search, specifically:

- ❑ What is the most versatile and suitable equipment to efficiently dewater/desludge lagoons in an environmentally safe fashion?
- ❑ Are there chemical/biological additives that can reduce/liquefy sludge effectively?
- ❑ How much reduction in the sludge accumulation rate can be expected due to a solid — liquid separation system in the manure stream ahead of an earthen structure?
- ❑ Can models be developed to more accurately estimate sludge buildup?
- ❑ What is the mineralization rate of nitrogen and other nutrients to be land applied from sludge and what is the salt content of sludge?

TABLE 1. Livestock Anaerobic Lagoon Sludge Characteristics

Species	Swine active[a]	Swine inactive[b]	Dairy[a] complete mix, sludge and supernatant	Dairy[c]	Poultry layer[a]
Units	mg/l (lbs/1,000 gal)	mgl (lbs/1,000 gal)	mg/l (lbs/1,000 gal)	mg/l (lbs/1,000 gal)	mg/l (lbs/1,000 gal)
Total Nitrogen					
Average	2,930 (24.4)	2,690 (22.4)	2,290 (19.1)	1,990 (16.6)	2,500 (20.8)
Std. Dev.	1,620 (13.5)	1,320 (11)	1,040 (8.7)	830 (6.9)	1,420 (11.8)
Total Phosphorus (P_2O_5)					
Average	6,310 (52.6)	1,550 (12.9)	5,020 (41.8)	1,070 (8.9)	9,260 (77.2)
Std. Dev.	4,120 (34.3)	940 (7.8)	3,940 (32.8)	540 (4.5)	4,790 (39.9)
Potassium (K_2O)					
Average	780 (6.5)	170 (1.4)	1,100 (9.2)	1,750 (14.6)	1,180 (9.8)
Std. Dev.	470 (3.9)	170 (1.4)	860 (7.2)	600 (5)	920 (7.7)
Copper					
Average	36 (0.3)	144 (1.2)	60 (0.5)	13 (0.11)	12 (0.1)
Std. Dev.	36 (0.3)	160 (1.3)	48 (0.4)	15 (0.12)	12 (0.1)
Zinc					
Average	96 (0.8)	140 (1.2)	84 (0.7)	19 (0.16)	130 (1.1)
Std. Dev.	72 (0.6)	72 (0.6)	48 (0.4)	11 (0.1)	120 (1)

a= Barker, J.C., J.P. Zublena, and C.R. Campbell. 1994. Livestock manure production and characterization in North Carolina. Agri-Waste Management Bulletin. Department of Biological and Agricultural Engineering, North Carolina State University, Raleigh, NC.
b= Sheffield, R. E. 2000. Sludge and Nutrient Assessment of Inactive Lagoons in North Carolina. Presented at the 2000 ASAE Annual International Meeting. ASAE Paper No. 004121. ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9659 USA.
c= Mukhtar, S. 2000. Assessment of Nutrients and Sludge from Dairy lagoons in Texas. (Unpublished data)

Published sludge accumulation rates are highly variable, but estimates can be made using Table 2 if field measurements are not available.

TABLE 2. Rates of sludge/solids accumulation in lagoons (modified from USDA-NRCS, 1992)

		Sludge Accumulation 1/hd/yr (ft^3/hd/yr)
Swine	Nursery	85 (3)
	Grow/Finish**	452 (16)
	Sows and litter	1,500 (53)
	Sows (gestation) and boars	395 (14)
Dairy	Lactating cows	10.755 (380)
	Dry cow	7,500 (265)
	Heifers	4,530 (160)
Beef	Feeder (high energy diet)	4,955 (175)
	Feeder (high forage diet)	5,660 (200)
Poultry	Layer	14 (0.5)
	Broiler	17 (0.6)
	Turkey	23 (0.8)

** Bicudo, et al. (1999) found a value of 203 l/hd/yr (7.2 cu ft/hd/yr).

REMEDIATION TECHNIQUES FOR MANURE NUTRIENT LOADED SOILS

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Many soils in the United States contain excessive levels of nutrients, especially phosphorus (P) due to repeated heavy applications of animal manure. Also, soils with a history of long-term poultry litter or swine manure applications have been found to have elevated levels of copper (Cu), zinc (Zn), selenium (Se), and arsenic (As). Runoff and eroded soils can carry soluble and bonded nutrients to water bodies and degrade their quality. Manure-treated fields can also impair air quality by emitting odorous compounds and dust. Several best management practices (BMPs) have the potential to reduce nutrients in runoff water and loading to surface waters. They can be grouped into two broad categories: (1) technologies to reduce excessive nutrient levels in the soil, and (2) technologies to reduce edge of field discharges of nutrients via runoff or sediment loss from over-application of manure or other organic biosolids. Potential remedial approaches for nutrient-loaded soils include:

- Phytoremediation (P, nitrate, metals) with plant species that preferentially bioaccumulate nutrients or metals and use of deep-rooted crops in novel rotations for subsurface nitrate-N recovery;
- Soil amendments with P immobilization chemicals and municipal or industrial by-products to reduce dissolved reactive P and metal bioavailability (water treatment residuals, aglime, coal combustion by-products);
- Addition of polyacrylamide polymers to reduce sediment and particulate nutrient offsite discharges (organic matter, N, P, metals);
- Deep tillage to dilute near-surface zone elevated nutrient concentrations and reduce odor emissions (P, metals, odor, trace greenhouse gases); and
- Conservation buffer strips to remove dissolved reactive P from runoff and reduce edge-of-field losses of sediments and particulate nutrients.

Growing high biomass yielding plants can remove large amounts of nutrients and may be a promising remedial strategy to export and reduce excess soil nutrients. Bermudagrass and certain warm-season annual grasses produce large dry matter yields, and thus, take up large quantities of applied nutrients. Cool-season grasses and certain legumes have a higher uptake of certain nutrients, such as P and may remove more specific nutrients than bermudagrass, although their yield potential is not as high.

Various plant species, including Brassica, preferentially concentrate Cu, Se and As from high metal soils. Using forage to extract P and specific metals in problem soils has been an effective approach, but is slow to lower soil levels. Grazed-only systems will not effectively remove nutrients from an over-application site since most of the applied nutrients, especially P and K, are recycled to the land during grazing.

Using soil amendments, research has shown that land application of drinking water treatment residuals potentially reduces dissolved P in runoff water by up to 70% from land with excessive levels of soil test phosphorus. Other materials such as fly ash from coal combustion in electric power generation and aglime are readily available and also effectively reduce P solubility in manure and manured soils, thus reducing the potential loading of agricultural P to nearby streams and lakes.

In addition to reducing runoff of dissolved nutrients, reducing particulate nutrient transport from nutrient-loaded fields depended heavily upon soil erosion control practices. The most widely studied and used methods to control soil erosion by water and wind involve a variety of conservation tillage methods for a wide range of soils and climatic conditions. Polymeric sediment flocculants are a promising component of an effective set of management tools to decrease sediment and sediment-associated nutrient loss. Land management practices such as deep tillage and conservation buffers also provide relief from offsite discharges and reduce the ecological risks of excessive nutrient levels.

Many remedial technologies exist to reduce the environmental degradation caused by agricultural land with excessive nutrient loads due to manure applications. We strongly feel that critical areas of needs for further soil remediation research and technology transfer exist and should include urgent efforts to:

❑ Identify and develop efficient nutrient and metal accumulator plants and profitable crop rotations for efficient nutrient and metal removal;

❑ Identify and develop efficient nutrient immobilizing chemicals and by-products for manure-derived P and metals;

❑ Identify and develop soil treatment and recovery technologies to produce value-added specialty products;

❑ Develop and apply geo-reference techniques to target remediation on field and watershed-scales; and

❑ Develop and evaluate the effectiveness of specific BMP systems in reducing manure nutrient export to the surrounding environment.

Integrated solutions are needed for managing excess manure nutrients in crop and livestock production systems. A combination of load reduction techniques and structural and cultural practices may be required to balance effectively the need to reduce soil nutrient levels and discharges from nutrient-loaded fields with the benefits of sustainable production of food and fiber and the need to protect natural resources and the environment for future generations.

EFFECTS OF MANURE AMENDMENTS ON ENVIRONMENTAL AND PRODUCTION PROBLEMS

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The purpose of this paper is to review the state of knowledge regarding the effects of manure amendments on environmental and production problems associated with manure from confined animal feeding operations (CAFOs). The main problems focused on in this paper are the ones that can be remedied, at least partially, by manure amendments. These include ammonia emissions, nitrate leaching, phosphorus runoff, pathogen contamination of food and water resources, and heavy metal runoff.

Problems Associated with Animal Manures

A large proportion of the nitrogen in animal manure is present as uric acid and urea. Shortly after excretion, uric acid and urea are hydrolyzed to ammonia, which can be lost via volatilization. While ammonia emissions from animal manure are dependent on several factors, manure pH has the largest effect. Ammonia emissions from animal manures to the atmosphere can cause several different problems, ranging from human health to production problems to environmental problems. Ammonia levels can reach high concentrations inside animal rearing facilities during the cooler months of the year, since ventilation of these facilities is minimized to avoid high heating costs. Both humans and livestock are sensitive to high levels of ammonia; exposure can result in poor animal performance and negative impacts on health.

The biggest environmental concern with respect to animal manures is currently phosphorus runoff, since is it normally the limiting nutrient for eutrophication. Eutrophication has been identified as the biggest water quality problem in United States surface waters. Since manure typically has a low nitrogen-to-phosphorus ratio, it causes a buildup in soil phosphorus, which may lead to high phosphorus runoff. However, even when soil test P levels are not high, phosphorus concentrations in runoff water can be high. The majority (80-90%) of phosphorus in runoff from pastures fertilized with manure is in the soluble form, which is the form most readily available for algal uptake. In fact, research has shown that the dominant variable affecting P runoff is the soluble phosphorus concentration in the manure.

Tens of millions of people are reported to have cases of microbial food-borne illness each year. One source of food-borne illness is meat contaminated with pathogens, such as *Salmonella*, *Campylobacter* and *Listeria*. These organisms are often present in manure of poultry and livestock. Although food-borne illnesses pose the greatest risks to humans from pathogens derived from animal manures, water quality can also be affected.

Animal manures, particularly poultry and swine manure, contain relatively high concentrations of heavy metals, such as arsenic, copper and zinc. These metals are normally high in manure because concentrations in the diets are high. High concentrations of heavy metals have been documented in runoff water from soils fertilized with animal manure.

Effects of Manure Amendments

Several different types of manure amendments have been used to control ammonia emissions, including clays, organic carbon amendments, microbial inhibitors, enzyme inhibitors, acids and acid salts. Since manure pH is the variable that has the largest effect on volatilization, the most common amendments used for ammonia control are acids. Weak acids, such as propionic and lactic acid, have been shown to reduce pH and lower ammonia emissions. Likewise, strong acids, such as sulfuric, nitric and phosphoric acid, have been shown to be very effective in controlling ammonia loss from manure. The problems with these acids are difficulty in handling (particulary strong acids) and increased phosphorus runoff for phosphoric acid. The most common manure amendments in the poultry industry are dry acids, such as aluminum sulfate, ferrous sulfate and sodium bisulfate. However, ferrous sulfate is no longer used, since it has caused toxicity catastrophic mortality in commercial broiler houses. One of the most effective (and cost effective) manure amendments for ammonia control is aluminum sulfate ($Al_2(SO_4)_3 \cdot 14H_2O$), commonly referred to as alum. Alum additions to poultry litter have been shown to reduce ammonia emissions by 99% in lab studies, resulting in much higher total nitrogen in alum-treated litter than normal litter. This increased nitrogen content in litter has been shown to result in significantly higher yields by crops. Studies conducted in commercial broiler houses with alum show that the addition of this compound to manure reduces the pH significantly for the first four weeks, resulting in a reduction in ammonia emissions by 75%. This reduction in atmospheric ammonia has been shown to result in improved weight gains, better feed conversion and lower propane use (due to decreased ventilation). Due to these production benefits, this BMP is cost effective, with a benefit/cost ratio of near two. Due to the positive environmental effects of alum, the USDA/NRCS is developing a conservation standard for the use of alum in poultry litter.

Little research has been conducted with manure amendments with the purpose of reducing nitrate leaching. The only method reported in the literature was to slow the conversion of ammonia to nitrate through the addition of nitrification inhibitors, such as nitrapyrin [2-chloro-6(trichlor-methyl)-pyridine], to manure to slow the nitrification process.

Manure amendments have also been used to reduce phosphorus runoff. Most of these amendments are aluminum, calcium and iron compounds that form insoluble phosphate minerals when added to manure. Since most of the phosphorus in runoff water from pastures is in the soluble form, the addition of these compounds reduces phosphorus runoff. Additions of alum and ferrous sulfate were found to reduce P runoff from tall fescue plots fertilized with poultry litter by 87 and 77%, respectively. Field-scale studies conducted on small watersheds have shown that phosphorus runoff is 75% lower from pastures fertilized with alum-treated poultry litter, compared to normal litter. Another aluminum compound that has shown promise for reducing phosphorus runoff is aluminum chloride, which may be more suitable for liquid manures, like swine manure, since it does not contain sulfate (which may result in hydrogen sulfide gas formation when added to liquid manures). The effects of waste products, such as fly ash and fluidized bed combustion (FBC) on soluble phosphorus in manures have also been evaluated. Although these results were promising, boron was released from these compounds at levels that would cause crop toxicities. It was also noted that calcium compounds have been used to precipitate P in manure; however, the resulting calcium phosphate mineral would not be stable in acidic environments. Another problem with adding basic compounds to manure would be the increase in ammonia emissions that would be caused by increasing pH.

Many manure amendments, such as acids, affect survival and reproduction of many different types of microorganisms, including pathogens. The effects of alum and sodium bisulfate amendments to broiler litter on *Campylobacter* and *Salmonella* colonization frequencies and populations have indicated that high rates of alum were 100% effective in controlling *Campylobacter* colonization on chickens. Although alum was not as effective at controlling *Salmonella;* alum treatments were significantly better than sodium bisulfate for *Salmonella* control at all times.

Sparse information is available on the effect of manure amendments on metal runoff. Two different studies have shown that alum applications to manure reduce arsenic, copper and zinc concentrations and loads in runoff water. This is believed to be due to the flocculating effect of this compound and subsequent reduction in soluble organic carbon compounds.

Research Needs on Manure Amendments

A systems approach is needed when studying the effects of manure amendments. Researchers need to evaluate how each amendment affects all of the problems, including ammonia emissions, phosphorus runoff, metal runoff, pathogens and crop yields. An economic evaluation should also be made on each amendment to determine cost effectiveness. Specific research needs are:

1. Determination of the effects of amendments on ammonia loss in various animal rearing facilities, including swine facilities, high-rise laying hen houses and milking parlours;
2. Documentation of the effects of manure amendments on ammonia losses throughout the production cycle, including once the manure has been land applied;
3. Evaluation of the effect of manure amendments on soluble phosphorus and phosphorus runoff (including long-term studies to make sure that the minerals formed are stable);
4. Evaluation of the effects of rates and timing of applications of manure amendments needed to reduce or eliminate pathogens at the farm level. Also the mechanisms of action of pathogen reduction need to be determined.

LEGAL STRUCTURES GOVERNING ANIMAL WASTE MANAGEMENT

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The federal government regulates Concentrated Animal Feeding Operations (CAFOs) under the constitutional authority of the Commerce Clause and the statutory authority of the Clean Water Act. Effluent guidelines for Feedlots Point Source Category are enumerated in the Code of Federal Regulations for large animal operations. These guidelines are implemented through National Pollutant Discharge Elimination System (NPDES) permits. Dissatisfaction with current federal provisions governing CAFOs led the Environmental Protection Agency to design a Proposed Rule to expand federal authority over polluting activities.

Livestock producers are concerned about the contamination of water, especially groundwater, and their potential liability for injuries. Persons injured by agricultural nutrients from Animal Feeding Operations (AFOs), including CAFOs, have several different legal arguments. Common law causes of action in strict liability, negligence, nuisance and trespass might be employed by aggrieved persons. Lawsuits based on these arguments would be brought by neighbors, not a very amicable situation in rural communities where most AFOs are situated. For nuisance causes of action, AFOs may qualify for the anti-nuisance protection of their state's right-to-farm law.

Due to shortcomings associated with the common law principles, governments have taken legislative steps to address the discord created by the activities and byproducts of animals. The federal Clean Water Act establishes federal standards for discharges from point sources of pollution and allows states to assume authority for regulating nonpoint-source pollution. The act's provisions complement the reserved authority of states to enact laws that enhance the welfare of their citizens. CAFOs in every state are subject to point-source pollution requirements. AFOs that are not CAFOs are governed by state nonpoint-source pollution regulations. In the past 10 years most states have enacted special laws addressing potential pollution by AFOs. Some of these go beyond federal point-source requirements or may address groundwater and air pollution. Local ordinances also regulate AFOs and the activities and practices that are possible in zoned areas. Aggrieved persons may select from a variety of statutory and regulatory provisions to seek relief for harm or from a burdensome situation.

The designated authority used by states in regulating AFOs varies considerably. Some states have assumed that their existing water pollution legislation provides authority for state agencies to adopt more detailed regulations that apply to AFOs. In these states no new legislation has been passed. Agencies have proceeded under existing laws to adopt regulations that safeguard the environment by restricting polluting activities by AFOs. In other states legislatures have enacted special legislation concerning AFOs. The laws may list various requirements or may direct a state agency to carry out the law. Based on these directions, the designated state agency adopts more detailed rules or regulations setting forth specific requirements for AFOs.

AFOs that are within the definition of a CAFO are point sources of pollution and must have a permit under the NPDES Program. AFOs that are not CAFOs are not required to have a federal permit, but a state may impose its own permit requirements. The Proposed Rule being advocated by the EPA seeks to increase the number of operations that would be designated CAFOs. By requiring more operations to have permits, the government hopes to curb nutrient pollution. To justify the new provisions of the Proposed Rule, the EPA cites data from the National Water Quality Inventory. But are the data supportive of the submitted provisions? An evaluation of the data's age, the amount of data on animal sources of pollution, the reported indicia of pollution, the referenced support for regulating the off-site application of manure, and pronouncements relating to agricultural storm water discharges disclose several conundrums. The shortcomings of the data raise the question whether some parts of the Proposed Rule might be set aside because they are arbitrary, capricious or lack a rational basis.

Our laws and regulations set forth a number of governmental enforcement mechanisms to respond to violations. In many cases a decision to prosecute involves the quality and quantity of resources and personnel available for responding to problems. Even with enough resources, there can be a problem with the agency's commitment to enforcement. Under the cooperative federalism incorporated in most environmental statutes, federal agencies commission states to enforce federal laws. For enforcement of laws under the management of the EPA, an annual enforcement agreement is executed between the state and EPA regional office setting forth enforcement commitments. Agencies in charge of carrying out environmental legislation may lack the authority to prosecute violations. Instead, they must refer violations to the attorney general.

The regulatory structure governing animal waste management suggests two major concerns. First, do governments have a problem with enforcing existing regulations, and what does this mean? Inadequate enforcement efforts by governments appears to be leading to unauthorized pollutants being discharged into our country's waters. The unwillingness of governments to eliminate pollution from violators may culminate in the public calling for more regulations or recommending additional remedies for aggrieved persons.

Second, are nonpoint sources of pollution causing pollution that needs to be controlled? The lack of definitive data suggests that we do not have sufficient information to develop efficient regulations. Yet such does not mean that governments cannot continue with efforts to regulate nonpoint-source pollution. Because the Clean Water Act does not regulate nonpoint sources additional controls over this type of pollution are dependent upon other authority. Currently, state governments are in charge of devising appropriate controls on nonpoint-source pollution.

The Proposed Rule should facilitate greater remedial actions against point-source polluters. An allegation of a permit violation against a CAFO will provide a cause of action that is easier to prove than alternative grounds. Moreover, the Clean Water Act allows citizen suits. Enforcement action against CAFOs is not dependent on governmental action. With the expansion of operations classified as CAFOs under the Proposed Rule, citizens will have increased opportunities to sue polluters for permit violations.

INNOVATIVE POLICIES FOR ADDRESSING LIVESTOCK WASTE PROBLEMS

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Animal waste is one of the most persistent environmental problems affecting the nation. Waste products that originate in dairies, poultry and swine facilities, and pasture land are contaminating the nation's rivers and lakes and reducing the quality of groundwater aquifers. A significant body of legislation, specifically designed to curb this problem, has not been effective. We believe that there are three reasons explaining the inability of these current policies to deal adequately with waste management problems. They are:

1. The multimedia nature of animal waste problems;
2. Concern for the financial situation of small producers; and
3. Inadequate means of monitoring and enforcement.

In what follows, we discuss the implications of these three factors on future policy design.

Animal waste creates problems in multiple dimensions and media, a feature that existing regulation largely fails to address. For example, until recently, most policies developed to regulate land application of nutrients have focused on nitrogen applications, and little emphasis has been placed on controlling other contaminants such as phosphorus, odor, dust and pathogens. Combined with little regulatory monitoring, this situation has resulted in a buildup of pollutants on cropland, especially on the land in proximity to livestock operations.

There needs to be a directed effort to create a holistic approach to the problem through regulation of all significant types of pollutants. Regulatory standards, waste management technology performance criteria and other policy targets should be set within a framework that simultaneously addresses as many facets of the animal waste problem as possible. In addition, it is inefficient to restrict animal waste regulation to livestock production operations alone. Instead, it is essential for regulation to encompass waste transport and disposal in addition to waste generation. Successful implementation of this holistic approach to regulation calls for continuous emphasis on research that identifies the linkages for different manifestations of animal waste problems and their relationship to production practices. That is, policy makers are going to require a better understanding of the relationship between observable production activities (number of animals on a farm, disposal acreage and location) and the resulting waste products that may not be observable for individual farms. For new proposed guidelines to succeed, it will be important to be able to associate all pollution channels and parties to their corresponding routes and actions that lead to different environmental consequences.

Incorporating waste generation, transport and disposal into one holistic regulatory unit suggests that policies will likely need to be designed in order to impose regulation over geographical regions. These regional waste management control activities may lead to the establishment of regional waste management accounting systems. This means that regional water quality agencies or other regional waste control agencies should have information about the production and waste disposal activities of different facilities and be able to obtain aggregate perspectives in order to design and assess specific policy actions. One of the most important challenges of policy reform is the establishment of independent systems of monitoring that will follow waste management activities comprehensively.

The capacity of current policies to modify behavior is restricted by the requirement to consider the financial situation of producers when enforcing regulations and also by the exemption of integrators from liability for environmental damages caused by waste generation. The desire to maintain and preserve some of the small farming units that are engaged in animal production has resulted in the establishment of "economic achievability" constraints that prevent the use of both penalties and regulations that would threaten the economic viability of small operations. In addition, animal agriculture in the United States, and in particular the swine and poultry sectors, has undergone a process of transition. Most production of poultry and swine is done through contractual arrangements where the facility operators who raise the animals receive genetic materials and dietary requirements (feed) from integrators, who ultimately process and sell the final product. For the most part, these integrators are not held liable for animal waste problems.

There are two main reforms that can address these financial and ability to pay constraints currently placed on waste management regulation. First, the liability for animal waste management should be shared by both integrators and operators. The exact level of sharing should be subject to further research. In some situations, it may be desirable to assign full liability to integrators while establishing a regulation that enables integrators to protect themselves against mismanagement by contractors. In particular, when integrators are responsible for the establishment of new animal livestock facilities and dictate the specifications of production facilities, they should also be responsible and liable for the waste management implications of their activities. Second, the desire to sustain small animal producers should be expressed explicitly in policy by introducing a system of green payments and other incentives for environmental services provided by farmers in animal waste control. In other words, it is better to provide explicit subsidies to allow financially constrained farmers to comply with strict regulatory standards rather than to weaken regulatory standards through implicit economic achievability subsidies, as is done at present.

The emphasis on holistic solutions that also incorporate the responsibility of the integrator and view waste management problems within a regional context may lead to the development and adoption of new technologies. In the past, the most effective method for waste management was recycling waste and using it as a crop fertilizer. It may be that with today's technologies, other types of recycling activities are now feasible. It may be possible to use waste products to fertilize exotic species (e.g. algae and duckweed) or use them as new sources of energy. In any case, government efforts should support basic research to find alternative mechanisms to dispose of waste products and to improve technologies for monitoring waste flows, thus enabling the transfer of waste regulation from a nonpoint to a point source pollution problem.

Animal waste regulation is also constrained by the problems of monitoring and enforcement. Frequently, water contamination is a non-point pollution problem (i.e., it is difficult to identify the exact source of a particular pollution) and, therefore, it is costly to monitor the economic activities that lead to the generation of waste and the ultimate contamination of water and other media. In the situations where regulation has tried to control waste disposal by restricting field applications below agronomic rates, excessive waste has been exported to off-farm fields, but its ultimate disposal was not adequately monitored.

One way of addressing the problems of monitoring and enforcement is to fund public sector research to develop technologies that will provide indicators on the origin of waste products. Research of this kind should be a major priority. Such technology will transform animal waste non-point source problems into point source problems, thereby simplifying monitoring and enforcement. Another direction for research, as mentioned above, should be to obtain a better understanding between observable activities (number of animals on a farm, the farm's disposal acreage and location) and the resulting waste products that may not be observable for each individual farm.

Improved information on pollutant emissions, as described above, can make it possible to increase the economic efficiency of regulation through the use of incentive systems such as the introduction of animal production or manure disposal trading rights. This type of system could be implemented in several ways. One alternative is the development of waste disposal rights that could be issued and traded in a market. Animal waste operators who own disposal lands could be allowed to dispose of a certain amount of waste products on a per unit base, and these rights would be tradable. Furthermore, landowners who do not own animals may also be given rights to use their lands to dispose of animal waste. This system could lead to the establishment of economic markets for animal waste disposal. Of course, regional authority will have to monitor overall groundwater quality and other environmental conditions in order to establish parameters for these markets. Environmental authorities also have to develop a monitoring system of growers' and farmers' activities and establish penalties when disposal levels exceed acceptable limits.

PATHOGENS IN ANIMAL WASTES AND THE IMPACTS OF WASTE MANAGEMENT PRACTICES ON THEIR SURVIVAL, TRANSPORT AND FATE

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Introduction

Manure and other wastes (such as respiratory secretions, urine and sloughed feathers, fur or skin) of various agricultural (livestock) animals often contain high concentrations (millions to billions per gram of wet weight feces) of human pathogens (disease-causing microorganisms). Per capita fecal production by agricultural animals such as cattle and swine far exceeds that of humans, and the trend for production facilities to harbor thousands to tens of thousands of animals in relatively small spaces results in the generation of very large quantities of concentrated fecal wastes that must be effectively managed to minimize environmental and public health risks.

Pathogens

As shown in Table 1, animal pathogens posing potential risks to human health include a variety of viruses (such as swine hepatitis E virus), bacteria (such *Salmonella* species), and parasites (such as *Cryptosporidium parvum*), some of which are endemic in commercial livestock and difficult to eradicate from both the animals and their production facilities. Hence, pathogens in animal manure and other wastes pose potential risks to human and animal health both on and off animal agriculture production facilities if the wastes are not adequately treated and contained. There are also growing public health concerns about the high concentrations of antibiotic-resistant bacteria in agricultural animals resulting from the therapeutic and growth-promotion use of antibiotics in animal production. This report reviews: (1) the types of pathogens potentially present in the manure of swine and other agricultural animals, (2) the levels of some important microbial pathogens and indicators for them that have been detected in animal wastes, (3) the potential for off-farm release or movement of pathogens present in manure and other wastes under current or proposed management practices, and (4) the extent to which these pathogens are reduced by currently used and candidate manure treatment and management technologies.

Table 1. Some Human Pathogens Potentially Present in Animal Wastes

Viruses/Groups:	Hepatitis E virus (swine), Reoviruses, Rotaviruses, Adenoviruses*, Caliciviruses*, Influenza viruses (Orthomyxoviruses)*
Bacterium/Group:	*Salmonella* spp., *Campylobacter* spp., *Escherichia coli* **, *Aeromonas hydrophila***, *Yersinia enterocolitica, Vibrio* spp., *Leptospira* spp., *Listeria* spp.
Parasites (Protozoans):	*Cryptosporidium parvum, Giardia lamblia*, and *Balantidium coli*

*Humans and animals (including swine) usually have distinct strains of these viruses, but not always.
**Some strains of these bacteria are non-pathogenic and others are pathogenic. The extent to which pathogenic strains occur in animal wastes varies with the animal species and other factors.

Some of the important pathogens potentially present in animal manures are not endemic in the United States, but there are growing concerns that such non-endemic pathogens may be introduced either accidentally or deliberately. Newly recognized or emerging livestock animal pathogens with uncertain host ranges continue to be discovered, and there are concerns that these pathogens, such as hepatitis E virus and orthomyxoviruses (influenza viruses), may be able to infect humans.

Pathways for Pathogen Movement on and off Farms

Pathogens from animal manures and other wastes have the potential to contaminate water, land and air if containment and treatment do not adequately manage the wastes. Pathogens are capable of persisting for days to weeks to months, depending on the pathogen, the medium and the environmental conditions. Many treatment and management systems for animal manure are based on the principle of no discharge and the recycling of manure constituents on the farm. However, off-farm movement or transport of animal waste pathogens has occurred via water, air and other media and is an infectious disease concern within the animal industry. Pathogen contamination of farm workers is also possible, and infection of farm workers can lead to further transmission of pathogens to family members and other contacts.

Pathogen Reductions by Manure Treatment and Management Processes

Estimated pathogen reductions in animal manures are summarized in Table 2. The reductions of some pathogens by some animal waste treatment processes have been determined in laboratory and pilot scale field studies. In general, thermophilic processes, such as pasteurization, thermophilic digestion and composting, are capable of producing extensive (>4 $\log_{10}$) pathogen inactivation, and therefore, resulting treated residuals are likely to contain only low pathogen concentrations. Further studies are recommended to better characterize pathogen inactivation in thermophilic processes for manure treatment and to define the optimum conditions to achieve extensive pathogen reductions.

Drying of some animal manures is a widely practiced management approach in some places. However, little is known about the extent to which pathogens are inactivated in manure drying processes or during dry storage because there have been few if any studies to document their effectiveness. Desiccation or drying to very low moisture levels (<1%) has been shown to result in extensive (>4 $\log_{10}$) inactivation of pathogens in municipal biosolids and in soils. Therefore, studies are recommended to determine the rate and extent of pathogen inactivation in drying and desiccation processes for animal manures.

Most mesophilic biological treatment processes for animal manures are not likely to reduce pathogen levels by more than 1-2 $\log_{10}$ or 90-99% unless several treatment reactors or processes are used in series. Therefore, treated manures, effluents or biosolids from such processes may still contain high concentrations of pathogens. The fate of these pathogens in subsequent management operations, such as land application or prolonged storage, is uncertain and has not been adequately determined. Therefore, further studies on effectiveness of mesophilic treatment processes in reducing pathogens and on the fate of pathogens in these post-treatment management processes are recommended.

Chemical treatments of animal manures are typically by lime or other alkaline treatment. Such treatment is widely practiced for municipal biosolids but less so for animal wastes. Alkaline stabilization for pathogen inactivation has been highly effective in municipal biosolids, and promising results have been obtained when it has been applied to animal biosolids. Therefore, further studies are recommended to better characterize pathogen inactivation by alkaline treatments of animal biosolids with respect to solids composition, pH and storage and handling conditions.

Summary, Conclusions and Recommendations

Pathogen reduction by animal waste treatment processes and management systems has been studied only for a few microbes, primarily indicator bacteria such as fecal coliforms. Therefore, removal and inactivation of the many different

TABLE 2. Summary of Animal Waste Treatment Processes and Estimated Pathogen Reductions

Treatment Process	Est. Pathogen Reduction (log_{10})	Comments
Physical		
Heat/Thermal Processes		
Mesophilic	Typically, 1-2	Depends on temperature, pathogen, contact time, pH, etc.
Thermophilic	Typically, >4	Depends on temperature, pathogen, contact time, pH, etc.
Freezing	Variable	Depends on pathogen, waste composition and conditions, temperature, etc.
Drying or desiccation	Typically >4 at <1% moisture; Typically <1 at >5% moisture	Depends on pathogen, contact time, pH, etc.
Gamma Irradiation	Typically >3	Varies with pathogen, dose, waste, etc.
Chemical		
High pH (>11)	Inactivation at high pH, e.g., alkaline/lime stabilization; >3-4	Varies with pathogen, contact time, pH, etc.
Low pH (<2 to <5)	Inactivation at low pH; acidification: typically, <2	Depends on pathogen, contact time, pH, etc.
Ammonia	Inactivation at higher pH where NH_3 predominates	Varies with pathogen, contact time, pH, other waste constituents
Biological Processes		
Aerobic, mesophilic	Typically 1-2	Varies with pathogen, solids separation, contact time, reactor design, temp.
Aerobic, thermophilic (composting)	Typically >4	Depends on pathogen, solids separation, contact time, reactor design, mixing methods, temperature
Anaerobic, mesophilic	Typically 1-2	Depends on pathogen, contact time, reactor design, solids separation, temperature
Anaerobic, thermophilic	Typically >4	Depends on pathogen, contact time, reactor design, solids separation, temperature
Silage treatment, mesophilic	Variable	Depends on ensiling conditions and pathogen
Land application	Highly variable and largely unknown; potentially high	Depends on site-specific factors: temperature, precipitation, vadose zone, loading, sunlight, riparian buffers, etc.

kinds of pathogens in various waste treatment processes and management systems is uncertain and needs further investigation. Although land application systems also influence pathogen survival and movement, this has not been extensively studied either. Stored manure also can attract vectors, and these vectors can either introduce or spread pathogens. Therefore, there are considerable uncertainties about the extent to which various pathogens survive waste treatment processes, are released into the environment and are available to be transported off of farms. Off-farm contamination can potentially occur inadvertently, such as in unplanned and uncontrolled releases by runoff, aerosolization or infiltration into soils and groundwater, or it can occur purposefully when biosolids and other manure residuals are transported off of farms to be land applied, marketed or for other beneficial uses.

The ultimate fate of manure pathogens remains especially uncertain for large-scale, multi-stage systems employing treatment or storage followed by land application at production facilities with large numbers of animals and minimum acreage (confined or concentrated animal feeding operations). Because of the magnitude of the quantities of animal wastes generated by these facilities and the potentially high pathogen loadings that can result if the treated manure residuals still contain high pathogen concentrations, further investigation of the fate of pathogens in these systems and their surrounding environments is recommended.

Definitive or reference methods to recover and detect many of the pathogens in animal manures and their treated residual solids and liquids are lacking, especially for hyper-endemic or emerging pathogens, such as hepatitis E virus, bacteria such as *E. coli* O157:H7, *Salmonella typhimurium* and *Yersinia enterocolitica*, and parasites such as *Giardia lamblia* and *Cryptosporidium parvum*. Therefore, the extent to which these pathogens are removed, inactivated or persist in animal waste treatment processes and management systems remains uncertain due to the limitations of the recovery and detection methods. The development, evaluation and application of reliable, sensitive and affordable methods to recover and detect pathogens in animal manures and their treated residual solids and liquids are recommended.

Methods are available to recover and detect some fecal indicator microbes in animal manures and their treated residual solids and liquids. However, the methods for some indicators, such as bacterial viruses (coliphages) and spores of *Clostridium perfringens*, have not been adequately verified and collaboratively tested in these types of samples. Such verification and performance characterization studies are recommended. Also recommended are comparative studies on the removal, inactivation and fate of indicator microbes and animal pathogens in manure treatment processes and management systems. If such studies show that indicator microbes reliably reflect or predict the responses and fates of animal pathogens in manure treatment processes and management systems, then the indicators can be used in practical, rapid and affordable monitoring and surveillance activities to assess treatment process and system performance and the pathogen quality of treated residuals.

PRACTICAL ASPECTS OF MANURE MARKETING

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Concerns about potential environmental impacts from traditional land application of animal manure have increased substantially in the past 20 years. It is inevitable that animal agriculture must embrace alternative management strategies for animal biomass, particularly given the areas of concentrated production and the relatively high nutrient content of manure. These management strategies will, by necessity, focus on what to do with *excess* manure, i.e., manure that can no longer be applied to agricultural lands due to environmental concerns. It has become widely recognized that exporting excess manure — from the farm, from the watershed, or even from the entire area of concentrated animal production — is the best option for avoiding excessive nutrient loading in such areas.

Animal biomass export — whether in raw or processed form — is more often than not economically challenging under current (or near term) economic conditions. Individual producers typically have limited financial resources available from their operations to ameliorate environmental concerns in an economically feasible manner without substantial reorganization of manure handling systems. Except for a few instances around the country, export activities have proved *not* to be economically viable

Land-applied manure as a fertilizer is, in the near term, likely to be the most economical means of disposing of animal biomass in many areas. Absence of formalized and sufficient marketing arrangements is a principal obstacle to increasing the use of manure as fertilizer in regions of concentrated animal production. At present, farmers rely largely on informal, case-specific arrangements that meet the idiosyncratic needs of individual parties for disposal of manure off their own farms. But these arrangements are difficult, if not impossible, to extend on the broad scale necessary to address the environmental and economic problems that have arisen in the past few years for a number of reasons. The exact nutrient content of the manure varies with producer and would be difficult to specifically verify. Differences exist in marketing requirements for different livestock species. Excess manure production is often a regionally isolated problem in areas of varying climate, topography, soil capabilities, production concentration, agricultural cropping patterns, age of production facilities and transportation infrastructure. These regions may be subject to varying environmental patterns and standards. Further complications arise when production is in conjunction with an integrated firm. In addition, there is a considerable lack of credible, specific information to allow a true evaluation of how much manure is being produced and what constitutes "excess" manure and how much of the excess to export to effectively address the problem.

Options for reorganizing handling systems possess a common characteristic: They must facilitate efficient and effective excess manure transport from concentrated production areas at a sustainable market price to result in proper utilization of manure. Low market price is the first and most critical factor to be addressed. Existing manure prices must be increased to levels that meet or exceed manure's spread costs and approach the product's true economic value based on its agronomic value. These prices will only be sustained if sufficient infrastructure exists to handle large quantities transported over long distances. If prices cannot be established through market forces, market interventions may be necessary. An additional potential approach is to increase the relative price of manure compared to chemical fertilizers by imposing an environmental tax on chemical fertilizers. Such a tax would also limit overuse of more soluble chemical fertilizer, especially with respect to phosphorus as a component of the fertilizers.

Additional specific factors affecting marketability of manure can be grouped into the broad categories of infrastructure and logistics and "market sentiment" of the various parties involved. Infrastructure to create brokerages or exchanges to affect manure ownership and location transfer is essential. Such infrastructure would include determination of minimum and maximum volumes and service areas as functions of prices, regulations, transportation and quality and acquisition/dissemination of price, quantity and quality information. Adequate transportation and acceptable timing of manure pick-up and delivery must also be guaranteed for an effective marketing system to be realized.

Although these factors certainly must be addressed to achieve a viable export program, the economics of litter export are the bottom line and will determine whether export programs move forward. On a case-by-case basis, potential export receiving markets must be delineated and cost-price relationships and market constraints must be identified. Likely impacts of functioning manure markets on supply and demand, including technological and contractual changes, should also be considered.

Coordination of manure marketing at the regional level by establishing a mechanism that can provide large-scale coordination of litter supplies and off-farm management, including export is a mandatory component of any long-term approach. There currently exists no developed excess manure market system capable of generating positive margins on a widespread and consistent basis, thereby effectively eliminating private sector participation as a/the solution to the problem. The existing independent contract producer structure and the independent litter service provider industry are not conducive (and do not have the resources required) to establish the centralized, regionally coordinated initiative needed for large-scale, high-efficiency litter supply coordination and export. A third party enterprise could effectively serve this function and provide a wide range of benefits for producers, integrators and others involved (directly and indirectly) in litter export activities.

Management of the excess under present conditions is a cost-incurring activity, not a revenue-generating activity. Therefore, it is necessary to view options from the perspective of how best to generate supplemental funds to allow efficient and equitable management of excess manure. Four broad categories of realistic options for addressing additional costs associated with alternative manure management practices are proposed: public sector market interventions, public sector incentives, private sector financing and augmenting incentives state or federal tax credits for managing excess manure in prescribed ways, investment tax credits for infrastructure development and permit waivers for those producers operating under an approved excess manure alternative management plan. Examples of operational incentive programs funded at the state level include those in Maryland and Virginia for litter transport and one in Texas for purchase incentives for composted dairy manure. Tax benefits that may be incorporated as augmenting incentives could be seamlessly handled by taxing local, state or federal authorities. Interventions and incentives should be viewed as mechanisms to jump start alternative manure management activities with proposed sunset provisions since it is likely that the economic value of the manure, at least in the case of easily transported manure from poultry, would rise to a break-even or better level within a few years as markets develop. Similarly, as risks decrease, elimination of these interventions could reasonably occur.

It is important to the industry that a level playing field with respect to costs continues to exist among the various production areas. That is, as regulatory pressures increase manure management costs differentially from region to region based on the regionally isolated nature of excess manure problems, producers in one region would hope that their competitive positions would be unaffected by these costs relative to another region. Various market interventions and incentives are available to the public sector and/or to the poultry industry that could resolve this impasse and enable animal agriculture in the United States to remain economically viable and competitive, including public sector market interventions (e.g., marketing orders, check-off programs, point-of-sale consumer taxes), public sector incentives (e.g., producer/transporter/end-user incentive payments), private sector financing (e.g., integrator compensation to growers), and augmenting incentives (e.g., tax credits). The interventions/incentives could be effectuated by industry-funded, consumer-funded and/or government-funded mechanisms.

ECONOMICS OF ANIMAL PRODUCTION/MANURE MANAGEMENT SYSTEM COST BENEFIT ANALYSIS TO IMPROVE SOCIAL WELFARE

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Economics is the study of the allocation of scarce resources for the purpose of maximizing the welfare of people. The white paper summarized here is a review and application of economics to the questions of how to improve social welfare via modifications to animal production systems and waste management systems and modifications to the policy and regulations that affect them. A comprehensive approach is taken in this paper building on principles of social welfare maximization, specification and measurement of benefits and costs and welfare effects of various modifications to policy and farm production systems. Emphasis is placed on: 1) the individual farm level response to policy (regulations, incentives and education), 2) the relationship between farm level practices and environmental quality, 3) the relationship between farm level decisions and the welfare of rural communities, and 4) the identification of efficient, equitable modifications to improve social welfare.

Welfare maximization is the major economic principle defining optimal policy. If welfare is not maximized, inefficient allocation of resources diminishes societal welfare and provides fewer resources to properly address the wants of society — including greater environmental quality. While the absolute maximum of social welfare may be impossible to identify, conditions for moving towards the maximum provide us with economic principles for decision making.

First, for a policy change to be welfare increasing, the benefits must exceed the costs. Second, for a policy change to be efficient, no other policy change should provide the same benefits at lower cost (or greater benefits at the same cost). Otherwise, welfare is not increased as much as it might have been and society again has fewer resources to distribute to competing ends.

An application of these two principles is that environmental regulation of livestock farms should only impose costs where the value of corresponding benefits is greater. An extension of these principles is that costs should only be imposed to the degree, and on specific farms, where the value of corresponding benefits is greater. Otherwise, individuals, communities, regions and society have lower welfare than they might have had.

Cost and benefit analysis is a common (and legally mandated) method of evaluating environmental regulations. Costs and benefits are estimated for both the producer (assumed source of pollutants, investment, income and employment) and the rest of society (assumed beneficiary of less pollution, more investment, income and employment). This paper addresses the process of cost and benefit analysis and its appropriate use in evaluating the economic impact of proposed environmental regulations.

Non-point source pollution policy presents compounded problems when estimating the costs and benefits of pollution abatement. For example, costs of regulation oversight may increase per unit of pollutant because literally tens of thousands of dispersed animal feeding operations and millions of acres are subject to record-keeping and verification. In other words, non-point source pollution agency costs may well be higher than point source pollution agency costs per unit of pollution abated.

Benefit estimation for non-point source pollution reduction from livestock farms is problematic due to the uncertain relationship between potential pollutants applied to a farm field and the actual transport of pollutants to a site where environmental damage can occur. Point source pollutants are clearly defined as pollutants when they are discharged directly into a susceptible environment by a man-made conveyance. The probability of potential non-point source pollutants causing environmental damage is conditional on the location of the field (source), management practices and exogenous variables such as weather. Unplanned pollution can occur from both point sources and non-point sources when systems fail (e.g. when a storage structure is breached, or a rainfall event transports a potential pollutant from its intended location). Implications for benefits estimation and policy design of non-point sources versus point sources are explored in the paper. The need for improved validation of fate and transport models is stated.

Assigning a monetary value to pollution reduction presents a second class of problems in benefit estimation. Markets for environmental quality losses due to pollution are rare. The value of benefits is therefore estimated (predicted) using some non-market method (e.g., contingent valuation) that may overvalue or undervalue the benefit. Regulatory agencies use an approach called "benefits transfer" to value improved environmental quality. An example of a pitfall in this predictive approach is that a constant marginal value (price) may be applied to ever increasing levels of environmental quality rather than recognizing that as the supply of environmental amenities increases their marginal value decreases, all else held constant.

A critical component of cost benefit analysis for welfare increasing policy design is an assessment of the distribution of impacts of the proposed policy. Averages can be highly deceiving in cases where the distribution of benefits and/or the distribution of costs are highly skewed across farms and across regions. For example, a very high fraction of the benefits of a policy change may be generated on a very small fraction of the farms being regulated. Similarly, costs of complying with a rule may vary widely by farm type, region or site specific conditions. Efficient policy design will incur costs primarily at the very small fraction of farms where most of the benefit is achieved. Inefficient policy will impose costs on farms and regions where little or no benefit is created.

Equity is an important consideration in designing policy change for livestock farms. Most policy changes result in costs being imposed on some individuals and benefits being received by others. Any policy change that imposes costs on any individual, firm, community or region is a selective appropriation of wealth by the government for reallocation to those receiving benefits. The distribution of impacts described above suggests that a small group of individuals, communities and regions could suffer large losses of wealth to create relatively small benefits for a large group of people. In the case of livestock farms, most of the individuals bearing costs will be farmers that designed their farms, invested heavily and operated their waste management systems under the guidance and in full compliance with government environmental agencies. Pareto optimal change (named after economist Vilfredo Pareto) can be defined as change that leaves no person worse off and at least one person better off than prior to the change. Note that change must be social welfare increasing to satisfy the Pareto optimality criterion. In addition, beneficiaries of the change must compensate those bearing the costs. Some concepts and mechanisms of equitable policy change for livestock farms are explored in the paper.

A critical component of cost benefit analysis is predicting farm managers' response to waste management policy (regulations, incentives and education). For example, managers' response to rules that provide negative incentives (increased paperwork and probability of fines) may be to seek a least cost solution including avoidance of violation detection. The solution may not reduce the probability of pollution if the decision maker discovers alternative methods of regulatory compliance. Producers may more willingly comply with regulations that provide positive incentives such as cost-sharing or increased access to markets.

Cost benefit analysis at the farm level must also account for the market (dis)incentives created by policy. For example, regulations that selectively define manure nutrients as pollutants discourage development of markets for manure. Crop producers needing nutrients will shun manure nutrients when commercial fertilizers are not defined as pollutants. Conversely, policy incentives for manure nutrient utilization can stimulate markets that reduce potential pollution from manure supplied nutrients.

A core component of this paper details how farm level costs are estimated from a systems perspective. This systems perspective is important for accurate assessment of the costs likely to be incurred on individual farms. As an example of pitfalls of inadequate analysis, a simplistic analysis might assume that regulatory compliance can be obtained with existing land application technology priced at current custom rates per gallon. New regulations change the business and production environment so that this assumption leads to errors. In this example, custom rates are actually conditional on application rate (gallons/acre). When regulations result in a decreased application rate, the custom charge per gallon will increase. The simplistic analysis underestimates the cost of compliance. As described in the paper, farm level cost analysis includes financial feasibility of investments and the imputed value of farmers' time spent performing regulatory imposed activities during certain production seasons.

The paper includes a discussion of common pitfalls in assessing and aggregating costs such as misuse of frequency factors, incorrect interpretation of publicly available data (e.g. USDA price projections), and ambiguity of the effects of rule implementation on actual production practices.

In summary, this paper is intended to provide background and some guidance in applying economics to modify policy and regulations and modify animal production and waste management systems to efficiently and equitably improve social welfare.

THE RELATIONSHIP BETWEEN CONTRACTING AND LIVESTOCK WASTE POLLUTION

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The policy discussions about the potential linkages between contracting and livestock waste problems have been focused on two sets of issues. One set relates to the emergence of livestock waste as a major environmental problem that requires urgent regulatory intervention. Implicit in this debate is the notion that animal waste-related environmental problems have been caused or exacerbated by the organizational structure of the livestock industry, notably its high degree of vertical integration via production contracts with independent farmers. Another set of issues relates to the design of regulatory policies that could be implemented given the existing organizational structures of various livestock industries.

As far as the emergence of animal waste as a major environmental problem is considered, the central objective of this paper is to try to answer the question of whether contracting worsens livestock waste management problems, how and to what degree? The evidence about the potential linkages between contracting and animal waste management problems presented in the paper fits into four categories. First, contrary to the widely held belief that contracting leads to larger scale production (more animals per operation) and thus larger volumes of waste per operation, the existing literature does not support the hypotheses that contract livestock producers tend to be larger than independent farmers. Second, farmers tend to apply livestock manure in excess of the amount that would require just substitution of the chemical fertilizer because by applying manure on any given field they not only receive the nutrient benefits of that application but also save on the transportation costs relative to applying the same manure on more distant fields. This result shows that the use of manure can be expected to worsen nutrient runoff and leaching from croplands regardless of whether the livestock producer is a contract operator or an independent farmer. Third, contract production results in high concentration of livestock production facilities in a few geographic areas. However, there is also a tendency for independent livestock producers to concentrate in certain geographical areas due to significant agglomeration economies. Fourth, given the fact that monitoring the nutrient content of feed and manure is costly and imperfect and each party cannot observe the effort exerted by the other party, the net benefits (cost) of nutrient application may fail to get incorporated into the payment schedule of a production contract. Therefore, the question of the division of responsibilities for providing inputs in livestock production and the resultant payment schemes used to settle the contracts become important for purposes of optimal contract design.

When it comes to designing an appropriate regulatory regime, the paper focuses on the question of how to apportion the burden of regulation among the contracting parties in a socially optimal way. The conclusions can be summarized as follows. First, in light of substantial multi-tasking problems, the regulation toward some form of a shared responsibility between the integrators and growers for manure disposal may render the currently used relative performance piece rate remuneration schemes obsolete. It is conceivable that rather then switching to fixed wage contracts as a method of rewarding their growers, integrator companies may gradually change their organization structure towards more company owned farms. Such an important shift in the industry structure away from contracting may have dire implications for local rural communities in many parts of the country. Especially strong impact could be felt in the Southeast, where many small family farms heavily depend on the supplemental income from contract poultry operations. Second, the incidence of anticipated increases in environmental compliance cost will depend on the market power of the integrator on the market for growers. In markets with absolute monopsony power of the integrator, the increased cost of environmental regulation will always be borne by the integrator, regardless of the initial design. If the market for growers services is such that growers are actually earning positive rents, then the incidence of costs depends on the distribution of bargaining power between parties as well as the presence of other regulatory and legal requirements governing the specification of the contract form. Finally, the anticipated move toward shared responsibility for accidental waste spills between the integrator and growers may or may not be welfare enhancing depending on the relative bargaining power of the integrator on the market for growers. In geographical areas where the competition for growers is fairly fierce, making integrators liable for environmental damages caused by the growers may not be theoretically justifiable. On the other hand, if the integrator is the only game in town and the probability of growers defecting to another integrator is low, making integrators liable for environmental damages caused by the growers may be socially optimal.