Chapter 2
Animal Agriculture and the Environment

The U.S. animal sector has undergone major structural changes over the past several decades, the result of domestic and export market forces, technological changes, and industry adaptations. The number of large confined production units has expanded, while animal production and feed production are increasingly separated. The total number of animal units increased by about 10 percent between 1987 and 1997, while the number of animal feeding operations (AFOs) decreased by more than half (Gollehon et al., 2001).

Growing concerns about the potential impacts of these changes on environmental quality have spurred local, State, and Federal action. Complaints about water quality and air quality (primarily odor) fuel most of the conflicts between the animal sector and the general population. The Environmental Protection Agency (U.S. EPA) revised Clean Water Act regulations in 2003 for controlling runoff of manure nutrients from the largest AFOs. At the State level, North Carolina entered a legal agreement with the State's largest swine producers to develop innovative waste management strategies that would replace uncovered lagoon and sprayfield systems as a means of storing and treating waste from large hog operations, in order to prevent a repeat of the massive damage to water resources caused by Hurricane Floyd in 1995 (Williams, 2004). Rules on the handling of poultry litter now protect water supplies in eastern Oklahoma, which has witnessed a sharp increase in large poultry operations (Cody, 2003). The South Coast Air Quality Management District in California has introduced new rules for handling and disposing of dairy manure in order to reduce ammonia emissions that have affected heavily populated areas downwind (Wilson, 2004). Iowa, Pennsylvania, Arkansas, and Kentucky are among States that have introduced rules for curbing water pollution, ammonia, and odor from AFOs (Patton and Seidl, 1999; U.S. EPA, 2002).

Environmental Impacts of Animal Production

The major source of environmental degradation from AFOs is waste products (manure, urine, and bedding material). Pollution from animal waste includes runoff of nutrients, organic matter, and pathogens to surface water, leaching of nitrogen and pathogens to ground water, volatilization of gases and odors to the atmosphere, and emissions of fine particulates. Pollutants can originate at several stages of production, including:

- Production houses where animals are confined;
- Manure storage structures such as tanks, ponds, and lagoons;
- Land where manure is applied.

The focus of this report is primarily on the various forms of nitrogen generated by manure. Nitrogen moves freely between the soil, air, and water, and

there is a high degree of interdependence between the forms and paths it takes. Nitrogen from manure is therefore capable of affecting the quality of more than one environmental medium.

Nitrogen Products From Animal Production

Nitrogen is found throughout the environment. It is required by all living things and is a critical crop nutrient. Seventy-eight percent of the atmosphere consists of elemental nitrogen gas (N_2), which is inert, does not affect environmental quality, and is unavailable to living organisms. However, during the past 50 years, large amounts of reactive N have been added to terrestrial systems—including ammonia, ammonium, nitric oxide, nitrogen dioxide, nitrate, and nitrite—through combustion of fossil fuels and production/application of synthetic and organic fertilizer (Follett and Hatfield, 2001). Reactive forms of nitrogen pose a potential threat to environmental quality because of their ability to combine with other compounds and create environmental problems (see box, "Ammonia and Nitrate in the Environment," p. 6). Emissions of reactive nitrogen from AFOs are substantial, and their control represents an important objective in improving environmental quality (NRC, 2003).

Water-Air Interactions

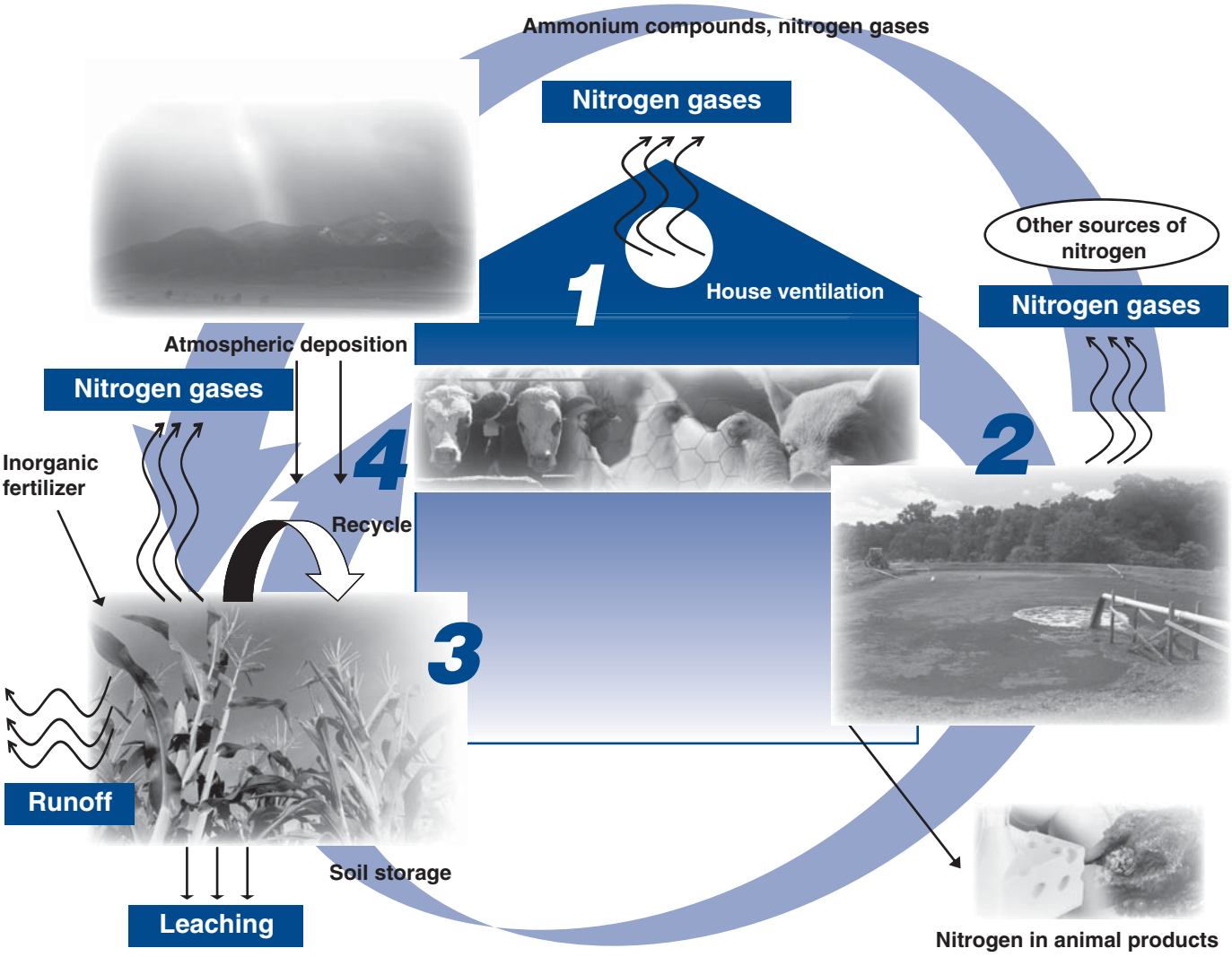
Emissions of nitrogen to water and to the atmosphere are not independent events, but are linked by the biological and chemical processes that produce the various nitrogen compounds (fig. 2-1). Nitrogen enters the system in animal feed. Some of the nitrogen is retained in the animal products (meat, milk, eggs), but as much as 95 percent is excreted in urine and manure (Follett and Hatfield, 2001).

Manure can collect in or under the production house for a few hours or several years, depending on the collection system. Production houses are ventilated to expel gases that are emitted, including ammonia. The manure is eventually removed from the house to a storage structure (lagoon, tank, pit, or slab) and stored anywhere from a few days to many months. Losses of nitrogen to air and water can occur during this time, depending on the system and the extent of contact with rain and wind. The stored manure is eventually transported to fields where it is applied. Losses to air and water from the field vary, depending on application method and rate. Nitrogen in the field helps produce crops, which may in turn be fed to animals, thus completing the cycle. Nitrogen lost to the air eventually returns to earth, where it can be a source of plant nutrients, or contribute to runoff or leaching to water resources.

The form nitrogen takes in its journey from animal to field depends on a host of factors, including storage technology, manure moisture content, temperature, air flow, pH, and the presence of micro-organisms. Reducing nitrogen movement along one path by changing its form will increase nitrogen movement along a different path (NRC, 2003). For example, reducing ammonia losses from a field to the atmosphere by injecting waste directly into the soil increases the amount of nitrogen at risk of moving to water resources as nitrate (Oenema, 2001; Abt Associates, 2000). Ignoring the interactions of the nitrogen cycle in developing manure management policies could lead to unintended and adverse effects on environmental quality.

Figure 2-1

Nitrogen follows many pathways in a livestock operation



The nitrogen cycle is a complex one, without a beginning, middle, or end. The principle of mass-balance ensures that the amount of nitrogen in a closed system is constant. Thus, any action to divert it from one pathway must necessarily transfer it into another. In this stylized figure:

1. Animals in the "house" release nitrogen in three ways: they produce manure (which then enters a storage system); they store nitrogen internally, which is bound in animal products distributed to markets; and they produce gases (directly and indirectly in manure production), which are released as air emissions;

2. Manure is stored in lagoons, tanks, pits, or other structures before being transported to fields for use as fertilizer;

3. Manure nitrogen applied to fields may be stored in the soil, leached into groundwater, run off into surface water, volatilize into air emissions, and be bound in crops; or

4. Nitrogen bound in crops may be used for feed for the animals, and the cycle begins again.

Nitrogen also enters and exits the system through intermediate pathways. For example, some of the nitrogen released into the air will settle back on the fields (deposition) and some new nitrogen will be added in the form of commercial fertilizer and nitrogen deposition from other sources.

Ammonia and Nitrate in the Environment

Two nitrogen compounds of particular environmental concern are ammonia and nitrate. Ammonia is a pungent gas that is a potential health hazard to humans and livestock. Nitrogen in animal manure can be converted to ammonia by a combination of hydrolysis, mineralization, and volatilization (Oenema et al., 2001). Once in the atmosphere, ammonia can be converted rapidly to ammonium aerosol by reactions with acidic compounds such as nitric acid or sulfuric acid. As an aerosol, ammonium contributes directly to fine particulates, the source of haze in the atmosphere. Gaseous ammonia that is not converted to ammonium is removed from the atmosphere by dry deposition, while ammonium aerosol is primarily removed from the atmosphere by rain or snow. Atmospheric deposition can cause ecological problems by changing plant communities through nutrient enrichment and soil acidification. Large quantities of ammonia are emitted from animal operations each year, making up 50 to 70 percent of annual ammonia emissions from all sources in the United States (NRC, 2003).

Nitrate is a highly soluble compound that is an important plant nutrient. In water, it can degrade water quality by spurring eutrophication. Nitrate can be a human or animal health hazard in drinking water if in high enough concentrations. The U.S. EPA has established a maximum contaminant level for drinking water of 10 ppm for nitrate-nitrogen. Nitrate enters water resources through runoff or leaching from fields receiving manure, or from leaks in manure storage structures.

Economic Relationships in Animal Waste Management

Farmers consider an array of factors when deciding about farm management and conservation practices. Production decisions are based on market prices, the farm's resources, available technologies, management skill, and expectations about weather. But incentives to consider environmental quality in the balance are often lacking.

How an animal feeding operation manages waste determines the paths of nitrogen and other manure constituents from production to disposal. Many practices are available for reducing gaseous emissions, runoff, and leaching (see box, "Manure Management Strategies"), but manure management practices with strictly public benefits (benefits realized off the farm) will be little used unless economic and regulatory conditions change.

Environmental policy incentives can be subsidies that favor a set of practices (technology incentives), requirements that certain practices be used (technology standards), or requirements that particular farm-level environmental goals be achieved (performance standards) (Ribaudo, Horan, and Smith, 1999). In each case, the farmer will choose that set of practices that maximizes net returns while taking into account the financial incentives or constraints introduced by policy. Whether environmental goals are subse-

Manure Management Strategies

Diet and health—Feed additives and improved nutrient utilization in animals' diets can simplify manure management at all stages of handling and disposal by reducing the amount of nutrients in waste (CAST, 2002; Abt, 2000). The goals of feed management are to match nutrient needs of animals more closely with nutrients in feed. Animal genetics, phase feeding (altering feed to match the age or production level of animals), and amino acid supplements are management tools that are currently available to animal producers.

Chemical addition—Chemicals can be added to manure during its collection in order to bind odorous compounds and to reduce ammonia emissions by lowering pH. For example, field tests indicate that alum can reduce ammonia emissions by 75-97 percent when added to poultry litter (Moore et al., 2000). Alum also increases the nitrogen content of litter that is eventually spread on fields, potentially increasing ammonia emissions from fields and loss of nitrate to water resources.

Air treatment—Trapping air vented from production houses and treating it before discharge to the atmosphere can reduce odorous compounds, ammonia, and other gases. Treatment processes include ozonation and biofilters (Jacobson et al., 1999). These processes do not affect the nitrogen content of manure.

Solid-liquid separation—Separating urea from solid fecal matter either mechanically or with sedimentation basins avoids some of the reactions that cause the formation of ammonia and odor. Separation also simplifies waste handling and disposal (Jacobson et al., 1999). While reducing ammonia emissions, separation preserves nitrogen in liquid and solid wastes, potentially increasing losses to air and water when eventually applied to fields.

Tank covers—Covering storage tanks can greatly reduce the discharge of ammonia to the atmosphere, primarily by altering pH and preventing the formation of ammonia (Jacobson et al., 1999). Storage tanks can be covered with a roof, concrete lid, or flexible plastic cover. The surface of the stored waste can also be covered with straw or other materials (polystyrene foam, air-filled clay balls). This material serves as a medium for micro-organisms that act as a biofilter. While reducing ammonia emissions, covers also increase the nitrogen content of effluent that is eventually spread on fields, increasing the potential for both ammonia emissions and loss of nitrate to water resources.

Lagoon covers—Plastic covers that float on the lagoon surface or that are tented over lagoons can greatly decrease gaseous emissions (Jacobson et. al.,1999, Arogo et al., 2002). Some systems (anaerobic digesters) also capture methane and use it as a biofuel to generate electricity. Covering a lagoon prevents the formation of ammonia by lowering the pH, but increases the nitrogen content of the effluent that is eventually sprayed on fields. While ammonia emissions from fields sprayed with lagoon effluent might increase, the net effect is a reduction in ammonia emissions from both lagoon storage and field applications. However, the risk of nitrate loss to water increases.

Manure incorporation and injection—Rapidly incorporating manure into the soil, either by plowing or disking solids after spreading or injecting liquids and slurries directly into the soil, reduces odor and ammonia emissions (Abt, 2000; Arogo et al., 2002). But, this also increases the nitrogen available for crops in the soil, and thus the risk of nitrate runoff to water resources.

Comprehensive nutrient management—Following a comprehensive nutrient management plan when applying manure and commercial fertilizer to land can reduce potential losses of nitrate to water resources through runoff or leaching (USDA, NRCS, 2005). Nutrient management matches nutrient applications to crop needs so that as few nutrients as possible are lost to the environment. Individual components include testing manure and the soil for nutrient content, calibrating application equipment, balancing crop needs with commercial fertilizer, and recordkeeping. Plans can account for atmospheric losses of nitrogen from animal operations, as well as atmospheric deposition of nitrogen on cropland.

quently met depends on how well the incentives are designed by the resource agency.

Policy Regime for Animal Waste

The major Federal environmental law currently affecting animal feeding operations is the Clean Water Act. AFOs concentrate animals, feed, manure, and urine in a small land area. Feed is brought to the animals rather than their grazing in pastures, fields, or on rangeland. The Clean Water Act specifies that AFOs may be covered by the National Pollutant Discharge Elimination System (NPDES) program (U.S. EPA, 2003). NPDES permits are required by point sources (facilities that discharge directly to water resources through a discrete ditch or pipe) before they can discharge into navigable waters. The permits specify a level of treatment for each effluent source. The regulations set thresholds for size categories based on the number of animals confined at the operation for a total of 45 days or more in any 12-month period.

Concentrated animal feeding operations (CAFOs) are AFOs that are designated by the U.S. EPA or State authority as requiring a point-source discharge permit. We estimate the number of potential CAFOs by using the December 2004 EPA specifications of CAFOs (see box, "EPA Size Thresholds") based on operation size. Large operations are considered CAFOs. Medium-sized operations *can* be designated CAFOs if a manmade ditch, pipe, or similar device carries manure or wastewater from the operation to surface water or the animals come into contact with surface water that runs through the confinement area, or the operation is designated by the permitting authority (typically the State). Even a small operation can be designated a CAFO by the permitting authority if it is found to be a significant source of pollution and it meets the above conditions.

The NPDES permits for CAFOs contain technology-based effluent limit guidelines for the production area and for the land receiving manure. A CAFO must have a nutrient management plan, covering the land receiving manure, that specifies an application rate for manure nitrogen or phosphorus based on the agronomic needs of the crops. EPA estimated that about 15,500 AFOs would be defined or designated as CAFOs (U.S. EPA, 2003).[1] This represents about 5 percent of U.S. AFOs, but covers about 60 percent of all confined animals.

Atmospheric emissions of pollutants are regulated by the Clean Air Act (CAA). The CAA authorizes regulatory programs primarily for protecting human health. EPA has recently initiated development of regulations for reducing fine particulates in the atmosphere (referred to as PM2.5, for particles less than 2.5 microns in size). The Clean Air Act requires State, local, and tribal governments to identify areas not meeting national air quality standards for fine particles (one of the six criteria pollutants regulated under the Act) (U.S. EPA, 2005). States with designated non-attainment areas must submit plans by February 2008 that outline how they will meet the standards by 2010. This regulation could affect animal operations because ammonia is a major precursor of fine particulates. Controlling ammonia from animal operations would be a likely priority in non-attainment areas with high concentrations of animals (U.S. EPA, 2000).

[1]A recent court ruling has brought into question how many CAFOs will actually need NPDES permits. It may be less than 15,500.

EPA size thresholds

Animal sector	Size threshold (number of animals)		
	Large CAFOs	Medium CAFOs	Small CAFOs
Cattle or cow/calf pairs	1,000 or more	300 - 999	Fewer than 300
Mature dairy cattle	700 or more	200 - 699	Fewer than 200
Veal calves	1,000 or more	300 - 999	Fewer than 300
Swine (over 55 pounds)	2,500 or more	750 - 2,499	Fewer than 750
Swine (under 55 pounds)	10,000 or more	3,000 - 9,999	Fewer than 3,000
Turkeys	55,000 or more	16,500 - 54,999	Fewer than 16,500
Laying hens or broilers (liquid manure handling systems)	30,000 or more	9,000 - 29,999	Fewer than 9,000
Chickens other than laying hens (other than a liquid manure handling system)	125,000 or more	37,500 - 124,999	Fewer than 37,500
Laying hens (other than a liquid manure handling system)	82,000	25,000 - 81,999	Fewer than 25,000

Source: U.S. Environmental Protection Agency.

Also covering air pollution is the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), enacted in 1980 to provide broad Federal authority to respond to releases of hazardous substances that might endanger public health. Section 103 of CERCLA requires that the person in charge of a facility immediately notify the National Response Center as soon as he has knowledge of any release in quantities equal to or greater than the "reportable quantity" (e.g., for ammonia, 100 pounds in a 24-hour period) of a hazardous substance. EPA is authorized to require remedial action when appropriate. Although CERCLA is focused on hazardous wastes from industrial plants, the increased size and consolidation of animal feeding operations may make their ammonia and hydrogen sulfide emissions subject to the notification provisions (U.S. EPA, 2005).

Neither the Clean Air Act nor CERCLA currently recognize CAFOs for regulatory purposes. There is no reason to expect that either of these laws would be applied to the same set of operations required by the Clean Water Act to meet nutrient application standards.

While environmental policies may not explicitly recognize the compound (air and water) effects of manure management practices, these interactions are well known to soil and animal scientists. NRCS specifically recognizes the potential air quality impacts of manure management practices that could be included in a Comprehensive Nutrient Management Plan (CNMP). A CNMP is a conservation plan unique to AFOs that addresses natural resource concerns dealing with soil erosion, manure, and organic byproducts and their potential impacts on water quality (USDA, NRCS, 2005). A CNMP must meet strict technical standards. NRCS recommends that AFOs consider the impact of selected conservation practices on air quality during

the CNMP development process. However, NRCS does not currently maintain technical standards for practices that address air quality concerns, so they are not included in a CNMP. In addition, CNMPs are not required of AFOs under EPA regulations. The nutrient management plan that permitted CAFOs must implement is not the same as a CNMP.

Multi-Path Emissions Have Unique Economic Implications

Pollution imposes costs on society that are not borne by the polluter. Thus, pollution control policies can increase societal welfare. Literature on the design of pollution control policies has almost exclusively focused on the control of one specific pollutant (Baumol and Oates, 1988; Tietenberg, 1990). The assumption that there is no interaction between pollutants, either in production or once emitted, is a strong one. Practical experience shows that this is not often the case.

When a production activity creates multiple pollutants or pollutes more than one environmental medium, correcting a single problem can lead to further resource misallocations (Lipsey and Lancaster, 1956). For example, Weinberg and Kling (1996) showed that addressing two pollution externalities associated with irrigation policy can increase welfare, even when the policies are introduced independently. However, there are situations where acting independently can lead to lower welfare than if one pollution problem was not addressed at all. Coordination of policies would ensure that an optimal mix of pollution control is achieved. Coordination is particularly important when policies are in conflict. When policies are complementary, addressing one pollutant tends to move the other in the desired direction. When policies are in conflict, addressing only one could worsen the other, even to the point of reducing overall economic welfare. Reducing soil erosion and improving water quality is an example of policies that can be in conflict (Conner et al., 1995; Lakshminarayan et al., 1995).

The multi-pollutant, multi-effect nature of air pollution has led to serious consideration of coordinated policies. For example, concern over the emission of acidic sulfur and nitrogen compounds in Europe led to separate protocols for reducing emissions of sulfur dioxide, nitrogen oxides, ammonia, and volatile organic compounds. Because of the synergistic effects of these pollutants in the atmosphere, and the multiple impacts on environmental quality (soil and water acidification, eutrophication, ozone formation), a combined approach offers the best means of achieving cost-effective control (Metcalfe et al., 1998; Michaelis, 1992).

One consequence of an uncoordinated approach is uncertainty about future regulations and how they might affect production. Uncertainty complicates a firm's investment decisions, in light of the significant adjustment costs and irreversibility of investment that capital expenditures generally entail (Lee and Alm, 2004). Policies in conflict would be particularly prone to this. If technologies and management measures implemented by CAFOs to meet water pollution regulations turn out to be in conflict with the goal of reducing air emissions, some of these measures might have to be abandoned, at significant cost to producers.

The compound and multi-pollutant nature of nitrogen flows in the environment suggests the importance of coordinated, rather than piecemeal, control (Bull and Sutton, 1998; Baker et al., 2001). In our chosen case of nitrogen from manure, CWA regulations require CAFOs to meet a nutrient standard for land application. This generally means more land is required for spreading manure than has been used in the past, an expensive proposition for many large farms (Ribaudo et al., 2003). One rational management response under a nitrogen standard is to encourage volatilization of manure nitrogen (e.g., use of uncovered lagoons, surface application to fields) to reduce the nitrogen content in waste, thus allowing higher application rates on cropland and reducing the amount of land needed for spreading (Sweeten et al., 2000). But, such a strategy would increase atmospheric emissions of ammonia and worsen air quality. Environmental policies that simultaneously consider all the environmental consequences of manure nitrogen may increase social welfare relative to single-medium policies when pollutant emissions are interdependent. Zilberman et al. (2001) cite the multi-path nature of animal waste as one reason why current policies are inadequate. A policy focused on nitrogen applications to land allows the buildup of other potential pollutants in the soil, such as phosphorus, and ignores problems such as odor and dust.

Ammonia Coefficients Used in This Report

While there are growing concerns over ammonia emissions to the atmosphere, the science behind developing a national ammonia emissions inventory and assessing ammonia management practices is lacking (NRC, 2003). According to the NRC, "There is a general paucity of credible scientific information on the effects of mitigation technology on concentrations, rates, and fates of air emissions from AFOs, (p. 5)." Much of this has to do with lack of appropriate monitoring technologies and procedures for measuring emissions from a nonpoint source.

However, we are not trying to estimate national emissions, but to assess tradeoffs in the nitrogen cycle (fig. 2-1). Recent research on manure management has provided useful information on the nature of these tradeoffs. We used as our starting point the manure management "trains" (MMT) developed by EPA (2004). This inventory of currently used animal production and manure management systems takes a mass balance or systems approach that is central to our study. However, these MMTs did not include management practices for reducing ammonia emissions. We adapted MMTs for systems incorporating recognized ammonia reduction technologies by using reduction efficiencies reported in the published scientific literature to redirect nitrogen along the appropriate paths. Table 2-1 shows the ammonia losses and the nitrogen available for crops for a set of common production and manure handling systems (with and without ammonia-reducing practices) that are used in this report to assess tradeoffs. The ammonia-reduction efficiency of lagoon covers (Jacobson et al., 1999; Arogo et al., 2002.; Oenema et al., 2001), incorporation (Moore and Meisinger, 2003; Hatfield, 2003; Jacobson et al.,1999; Abt, 2000) and alum (Moore et al., 2000) were obtained from the literature.

We make several assumptions to simplify our analysis.. We assume all CAFOs regulated under the Clean Water Act must adopt nitrogen-based nutrient management plans. An unknown number will probably have to adopt a phosphorus-based plan instead. Under such a plan, manure nitrogen

Table 2-1
Manure management systems and nitrogen losses

Animal	System	N excreted	Losses from building	Losses from storage	Losses from field	Total losses to air	Total available for crops
				Pounds N/head/year			
Hogs	Lagoon, uncovered	18.3	4.9	9.5	0.8	15.2	3.1
Hogs	Lagoon, covered	18.3	4.9	0.5	2.8	8.2	10.1
Hogs	Deep pit, surface apply	18.3	6	0	2.6	8.6	9.7
Hogs	Deep pit, incorporate	18.3	6	0	0.4	6.4	11.9
Dairy	Flush barn, surface apply	220	44	125	11.2	180.2	39.8
Dairy	Flush barn, incorporate	220	44	125	2.8	171.8	48.2
Dairy	Daily spread, surface apply	220	15.2	2.2	37.7	55.1	164.9
Dairy	Daily spread, incorporate	220	15.2	2.2	8.3	25.7	194.3
Poultry	Surface apply	0.9	0.18	0.03	0.17	0.38	0.51
Poultry	Incorporate	0.9	0.18	0.03	0.04	0.25	0.65
Poultry	Alum, surface apply	0.9	0.03	0.04	0.21	0.28	0.62
Fed beef	Solid storage, surface apply	102	0	20.8	13.8	34.6	67.4
Fed beef	Solid storage, incorporate	102	0	20.8	0.7	21.5	80.5

Source: U.S. EPA; Jacobson et al.; Arogo et al.; Oenema et al.; Moore and Meisinger; Hatfield; Jacobson et al.; Abt; Moore et al.

is generally applied at rates less than crop needs, so supplemental commercial nitrogen fertilizer is required (Ribaudo et al., 2003). Incentives to encourage nitrogen losses to the atmosphere would not exist in this case. Subsequently reducing ammonia emissions would not pose increased risks to water quality as long as compensating adjustments in supplemental commercial nitrogen fertilizer are made and the increased nitrogen content of manure does not exceed crop needs.

The Clean Air Act and CERCLA are national laws, but whether they affect animal operations depends on local conditions (non-attainment area in the Clean Air Act) or characteristics of individual operations (daily ammonia emissions under CERCLA). While these laws currently have only limited impacts on animal feeding operations, we do not attempt to forecast which regions or types of operations might be required to reduce ammonia emissions. Our goal is to demonstrate potential tradeoffs that could be important to farmers and to resource managers wherever animal feeding operations are required to meet water quality and/or air quality goals.

We also do not consider the fate of atmospheric nitrogen in our analyses. Atmospheric nitrogen can travel long distances, and our models cannot track its movement. Industrial and mobile sources also contribute significant amounts of atmospheric nitrogen. Accounting for atmospheric deposition would likely reduce the manure nitrogen application rates under a nutrient management plan used in our analyses, but would not alter our basic findings.