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Managing Manure To Improve Air and Water Quality

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Abstract

Animal waste from confined animal feeding operations is a potential source of air and water quality degradation from evaporation of gases, runoff to surface water, and leaching to ground water. This report assesses the potential economic and environmental tradeoffs between water quality policies and air quality policies that require the animal agriculture sector to take potentially costly measures to abate pollution. A farm-level analysis of hog farms estimates the economic and environmental tradeoffs that occur when policies are designed to address pollutant flows to one environmental medium without considering flows to another medium. A national analysis addresses the broader impacts of coordinated (water and air) policies, including long-term structural adjustments and welfare impacts on both producers and consumers. The report also analyzes the potential implications of adding air quality regulations to existing Clean Water Act regulations in the Chesapeake Bay watershed, where a limited land base increases producers' costs of meeting manure management requirements.

Keywords: Animal waste, nitrogen, ammonia, water quality, nutrient management plan, manure management costs, price and quantity adjustments, CAFO.

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Summary

U.S. environmental laws tend to focus on a single environmental medium (e.g., Clean Water Act, Clean Air Act, and Endangered Species Act). When a single pollution source can simultaneously affect more than one environmental medium, a single-medium approach to pollution control can confound policymakers concerned with economic efficiency. An uncoordinated set of policies that independently address different pollution issues can result in unnecessary and unanticipated economic and environmental costs.

Animal agriculture is facing just this situation. Animal agriculture produces a variety of pollutants, including organic matter, urea, ammonia, nitrous oxide, phosphorus, methane, carbon dioxide, pathogens, antibiotics, and hormones. Regulations to restrict animal farm emissions to the water might inadvertently increase emissions to the air, and vice versa.

What Is the Issue?

In 2003, EPA introduced revised Clean Water Act regulations to better protect surface waters from nutrients from concentrated animal feeding operations (CAFOs). When applying manure to crop or pasture land (the primary disposal method), CAFOs now must follow a nutrient management plan that specifies a manure application rate that minimizes the threat to water quality. The cost to farmers of meeting this requirement can be relatively high, primarily from moving manure to an adequate land base. A logical response by producers operating under a nitrogen-based plan might be to reduce the nitrogen content of manure spread on fields by enabling nitrogen to volatilize into the atmosphere from uncovered lagoons or by applying animal waste to land without incorporating it into the soil. But doing so also releases ammonia emissions into the air. As animal feeding operations are the primary source of ammonia in the United States, air quality regulations might require some States to regulate ammonia emissions from animal feeding operations.

What Did the Study Find?

Air and water quality regulations would be most cost effective if implemented simultaneously. This would allow farmers to select the most appropriate mix of practices that satisfy environmental quality goals while maximizing net returns. If environmental policies are uncoordinated, farmers may have to make costly changes to practices more than once before both environmental goals can be met.

To meet a water quality goal, farmers tend to use practices that increase ammonia emissions to the air. Similarly, the practices used to meet an air quality goal would tend to increase nitrogen losses from fields to ground and surface waters. Meeting both air and water quality goals would likely cost more than meeting either air or water goals.

Depending on how the air quality regulations are applied, this could have two impacts on CAFOs and water quality. First, farms identified as CAFOs might need to increase the amount of land on which they spread manure in

order to continue to meet nutrient application standards. This could be particularly costly in a region where animal concentrations are high and cropland available for spreading manure is relatively scarce. For example, requiring CAFOs in the Chesapeake Bay watershed to control ammonia emissions would increase producer costs of land-applying manure by $4 million per year. Failure to account for these costs when developing an ammonia regulation could lead to the false conclusion that the policy is efficient.

Second, an uncoordinated approach could reduce water quality. If ammonia reductions were required of both CAFOs and smaller farms, the water quality benefits from the regulations restricting CAFOs' nitrogen emissions might be diluted by increased nutrient applications on the smaller farms, which have no such nitrogen restrictions. In the Chesapeake Bay watershed, for example, the nutrient content of manure produced on farms not covered by a nitrogen application standard would more than double if ammonia restrictions were applied to all animal feeding operations. This would increase the risk of nitrogen runoff into the Chesapeake Bay.

Anticipating the different forms and pathways that nitrogen takes can keep air quality and water quality policies from working at cross purposes. Then, true solutions—like diet manipulation (to reduce the amount of nitrogen excreted by animals) or industrial uses of manure—might become clearer.

How Was the Study Conducted?

The study used three separate but related analyses to capture the full range of economic decisions (and consequences) that result from farmers' meeting environmental regulations. Data from the 1998 Agricultural Resources Management Survey of hog producers were used to estimate the tradeoffs that occur at the farm level when policies are designed to address pollutant flows to one environmental medium without considering flows to another medium. The broader impacts of coordinated policies, including the welfare impacts on both producers and consumers and regional shifts in production, were examined with a national model of the agriculture sector that tracks nitrogen losses to the environment. A case study of the Chesapeake Bay watershed was used to demonstrate the problems that hypothetical ammonia reductions would have for farms meeting the CAFO regulations in a region where land for spreading manure is relatively scarce, and for resource managers trying to reduce nitrogen loads.

At the heart of all three analyses are nitrogen loss coefficients that are derived from a mass-balance accounting of nitrogen in manure. These were obtained from EPA, and enabled us to estimate tradeoffs in nitrogen losses to the air and nitrogen applied to land as different manure management practices are employed.

Chapter 1
Introduction

U.S. agriculture produces affordable food and fiber for domestic use and export and contributes significantly to the economic base of rural communities. But many agricultural activities also produce pollutants that can harm the environment. For example, animal production generates byproducts such as organic matter, urea, ammonia, nitrous oxide, phosphorus, methane, carbon dioxide, pathogens, antibiotics, and hormones. Without proper management, these materials can degrade surface water, ground water, and soils. Environmental policy aims to improve the management of agricultural systems such that environmental harm is minimized.

Mitigating pollution problems can challenge policymakers when more than one environmental medium is affected by a single pollution source. The correction of a single problem without simultaneously addressing others may not increase societal welfare as much as anticipated, and may even decrease it. Thus, an uncoordinated set of policies that independently address different pollution issues could result in unnecessary losses in societal welfare. Scientists and program managers are also aware of these tradeoffs. However, environmental laws often focus on only one environmental medium (Clean Water Act, Clean Air Act, Endangered Species Act). Such narrowly focused programs may harbor large opportunity costs, especially with high interdependence in pollution flows between different environmental media (U.S. EPA, 1996).

Animal agriculture, in particular, has faced increasing environmental regulations in recent years. Growth and concentration in the industry over the past several decades has prompted concerns over environmental degradation in areas where production facilities are clustered. Concentrated animal feeding operations (CAFOs) have been regulated since 1974 under the Clean Water Act. CAFO regulations were strengthened in 2003 to reduce the threat of nutrients entering surface water, and were the subject of an earlier ERS study (Ribaudo et al., 2003). But these regulations do not require control of potential air emissions from CAFOs. Confined animal operations are the largest source of ammonia emissions in the United States (Abt Associates, 2000). Ammonia emissions have long been encouraged as a justifiable byproduct of meeting water quality goals (Sweeten et al., 2000). Lagoons, for instance, are commonly used to store and treat manure waste from swine operations. These storage systems volatilize nitrogen, thereby reducing its concentration in lagoon effluent and reducing the cost of meeting land application requirements. But, the volatilized nitrogen compounds escape into the air, creating odors, contributing to fine particulates (haze), and hastening global climate change (National Research Council, 2003). Only recently has ammonia loss been viewed as a potential problem in terms of air quality (Sweeten et al., 2000).

The current uncoordinated approach to air and water quality protection has potentially costly implications for both animal producers and society in general. Some animal feeding operations already subject to water quality regulations may soon be required to meet ammonia emission regulations. Technologies adopted to reduce water pollution may be inadequate for meeting both water quality and ammonia requirements, and might have to be abandoned or modified, at some cost, to comply with both sets of regulations.

Smaller operations not required to meet Clean Water Act regulations might be required to meet air quality regulations. If they change manure management practices to reduce ammonia emissions, the nitrogen content of the operations' manure will increase. If manure applications to the land remain unchanged, the risk of nitrogen runoff to water resources increases. A more coordinated approach to environmental quality protection could avoid these unintended consequences.

Research Objectives

This report assesses the potential economic and environmental tradeoffs between air and water quality when the animal sector is required to take potentially costly measures to abate pollution. To date, only a few analyses have discussed the cross-media problem (Helfand, 1994; Hohmann, 1994; Resources for the Future, 1996), and none explore the theoretical or empirical tradeoffs inherent in cross-media environmental policy. We extend this literature by acknowledging that multiple pollutants from animal feeding operations may enter different media; pollution control technologies effective in one environmental medium may conflict with technologies to control pollutants to other media. Examining the implications of regulating across environmental media may help guide future air and water quality regulations and improve the performance of existing policies.

To accomplish these objectives, this report:

- Reviews some of the potential pollution problems attributable to animal waste, the physical relationships inherent in the waste stream that complicate efficient manure management policy, and the environmental policy regime facing animal agriculture.
- Estimates the tradeoffs that occur at the farm level for hogs when policies are designed to address pollutant flows to one environmental medium without considering flows to another medium. This analysis best captures the production decisions that an individual producer makes when faced with market signals and regulatory requirements in the context of the farm's capital and resource bases.
- Analyzes the national impacts of coordinated policies, including the welfare impacts on both producers and consumers. This accounts for the price effects and regional adjustments missing from the farm-level analysis.
- Analyzes the implications of adding air quality regulations to existing Clean Water Act (CWA) regulations in a region where a limited land base increases the costs of meeting manure management requirements. This case study of the Chesapeake Bay watershed demonstrates how the costs of meeting CWA requirements are affected if ammonia emissions must also be reduced. It also demonstrates how water quality might be affected if ammonia reductions are required on farms not covered under the CWA.

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

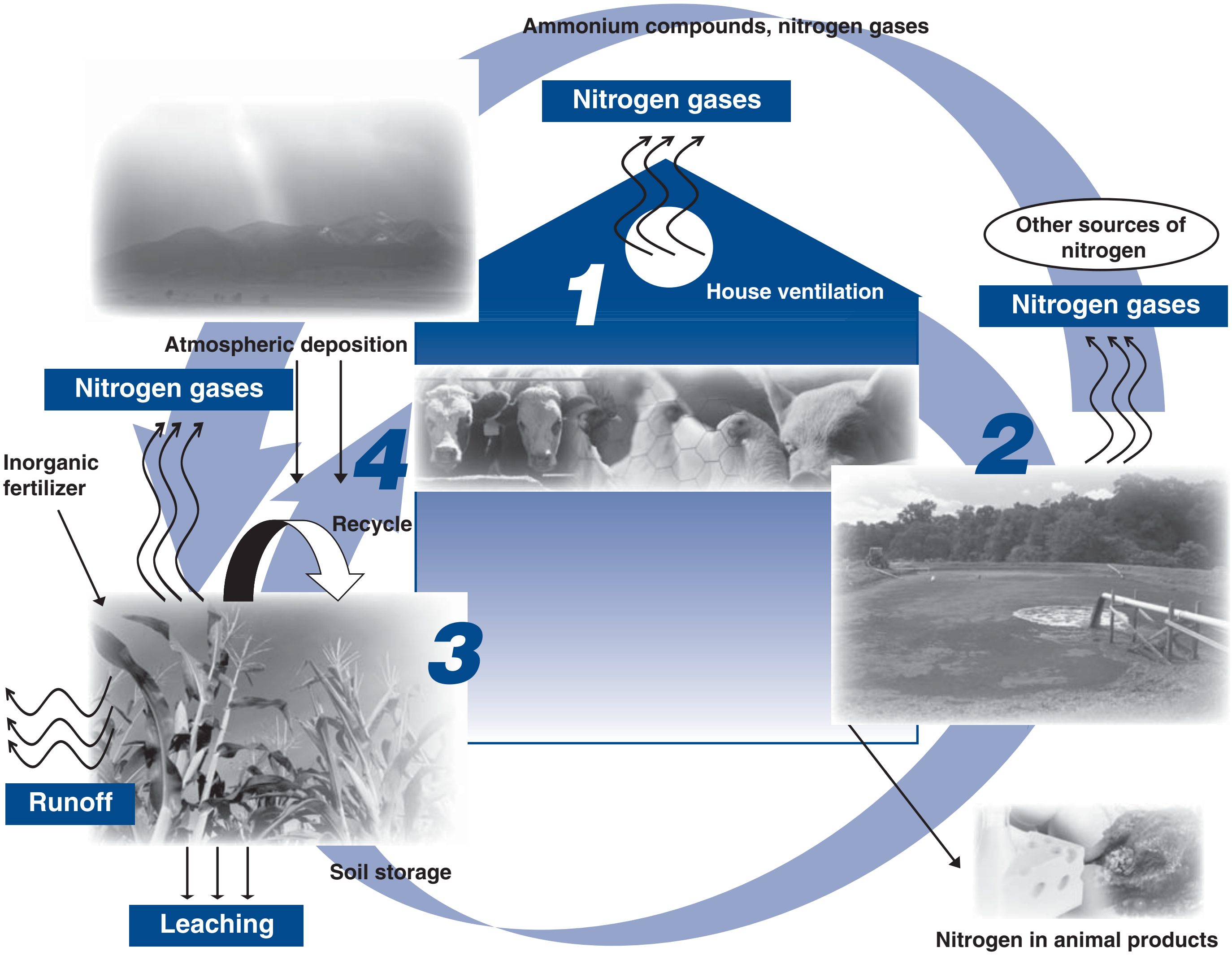
Emissions of nitrogen to water and to the atmosphere are not independent events, but are linked by the biological and chemical processes that produce the various nitrogen compounds (fig. 2-1). Nitrogen enters the system in animal feed. Some of the nitrogen is retained in the animal products (meat, milk, 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	Large CAFOs	Medium CAFOs	Small CAFOs
	Size threshold (number of animals)		
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.

Chapter 3

Water-Air Tradeoffs at the Farm Level

A farm-level perspective allows us to look at the economic decisions individual producers make to meet environmental goals, given previous management choices and farm characteristics. We examine the hog sector because it exemplifies the changes to scale, structure, and location that have occurred in the confined animal sector since the 1960s. In 1982, there were 175,284 farms with confined hogs, containing 6.3 million animals (USDA, ERS, 2005). By 1997, the number of farms had shrunk 64 percent to 63,723, while the number of hogs on these farms increased to 8.2 million (USDA, ERS, 2005). These larger facilities (in terms of animal units) are not necessarily larger in terms of cropland. Thus, 51 percent of the recoverable nitrogen (nitrogen remaining after manure handling and storage) in confined hog manure in 1997 was estimated to be in excess of crop needs at the farm level (Gollehon et al., 2001).

Most confined hog operations use either a slurry pit system or a liquid lagoon system for managing manure. Slurry systems store undiluted, untreated manure in watertight tanks or pits until it can be land applied. Storage can be either under the house or outdoors. The stored slurry is surface applied to fields by sprayer trucks or wagons, or incorporated into the soil with chisel plows behind nurse tanks, or directly injected into the soil with drag hoses. Most ammonia emissions from these systems are from the field where manure is applied (U.S. EPA, 2004).

Lagoon systems use open holding ponds to treat diluted manure for an extended period of time. Lagoons stabilize organic matter, reduce the nutrient mass that must be land applied, and vent a large quantity of the manure nitrogen as ammonia. Some of the diluted lagoon liquid is used to flush the production houses. The “digested” lagoon liquid is eventually sprayed on cropland. Lagoons are used primarily in warmer climates where the anaerobic processes can take place year round. Lagoon systems emit more ammonia per animal unit to the atmosphere than do slurry systems (U.S. EPA, 2004).

Because of the high cost of transporting manure relative to the value of the nutrients in the manure, farmers have an incentive to overapply manure to land located near their livestock facilities. The amount of manure generated on CAFOs and its estimated nutrient content indicate that 82 percent of hog CAFOs were overapplying manure nitrogen in 1998 (Ribaudo et al., 2003). Farmers can reduce threats to water quality by testing soil and manure for nutrient content, and applying nutrients at rates consistent with the agronomic needs of crops. Such an approach could force farmers to spread manure on more land, often requiring manure to be transported greater distances from the hog facility (Ribaudo et al., 2003). Farmers faced with nitrogen application restrictions through a required nutrient management plan—but not ammonia emission restrictions—might try to reduce the nitrogen content of manure as a means of reducing the amount of land needed for spreading, and limiting hauling costs. The nitrogen content of manure can be reduced by promoting the creation of ammonia and its volatilization to the atmosphere. This can be done by storing manure in uncovered lagoons and by surface applying slurry rather than injecting it (Sweeten et al., 2000). For example, the nitrogen available to crops in lagoon liquid is 70 percent lower when coming from an uncovered lagoon rather than a covered lagoon.

If, on the other hand, farmers face restrictions in ammonia emissions but not runoff, they can reduce emissions by adopting storage structures and management methods that reduce manure's contact with the air and maintain a low pH. Preventing the formation of ammonia preserves the nitrogen content of manure, increasing the availability of nitrogen for crops, as well as the risk of nitrogen loss to surrounding waters if the land base receiving lagoon liquid stays the same.

To examine the effect of potentially conflicting policies on a farmer's production decisions, we constructed a hog farm economic model. We evaluate three scenarios: (1) a nitrogen application standard as part of a nutrient management plan required by the 2003 CAFO regulations under the Clean Water Act, (2) a hypothetical ammonia emission standard based on available emission abatement technologies, and (3) a coordinated policy that meets both land application and ammonia emission standards. A positive mathematical programming model with calibrated cost functions captures the essential farm-level tradeoffs between air emissions and water discharges of nitrogen (see Appendix A—web only—for details). Farmers maximize profits given input prices, output prices (hogs and crops), regulatory requirements, and available cropland by choosing a manure management technology, the amount of land on which to spread manure, the acreage of each crop to plant, the amount of commercial fertilizer to purchase, and the number of hogs to produce. We assumed that the basic manure storage system (pit or slurry) would not change.

In the model, nitrogen enters through the feed ration and is retained by the animals or excreted in manure. Once excreted, the nitrogen may be released into the atmosphere through ammonia emissions or preserved in the manure storage and handling system until it is applied to cropland. Nitrogen enters cropland through commercial and manure fertilizer applications. The crop retains some nitrogen, some is bound in the soil substrate, and some is released directly into the environment through air emission and water runoff. Water quality impacts are assumed to be directly related to the amount of nitrogen applied to cropland that is in excess of crop needs, after losses to the atmosphere. Air emissions are derived from total animal production and the type of storage/handling technology employed by the animal feeding operation.

The model is calibrated with data from the 1998 USDA-ARMS survey of hog operations, the most recent survey for hogs. In the analysis, eight representative CAFOs are depicted, corresponding to four major hog producing regions (East Corn Belt, West Corn Belt, Mid-Atlantic, and South and West) and two major manure storage technologies (lagoon and pit). We consider two technological options currently available to hog farms that influence the level of ammonia released to the air: the injection of manure into the soil and covering lagoons.

Single-Medium Environmental Policies

Baseline

Model results indicate how the two single-medium policies and a joint multimedia policy would alter farmers' decisions affecting production, input levels, nitrogen to soil and air, and the use of emission technologies relative to the baseline year 1998—the year of the survey to which the model is calibrated. Baseline costs and profits reflect production decisions made in the absence of any regulatory constraints. In the baseline year, all hog manure was applied onfarm to corn, soybean, and other crops at a rate 7.3 times greater than the nitrogen-based agronomic rate (table 3-1, column 1). This rate reflects the quantity of manure produced by farms relative to the amount of land on which manure was spread in 1998 and the crops reported as receiving manure. In the baseline year, about 10 times more ammonia nitrogen is released from manure storage facilities (lagoons and pits) than from fields. Total nitrogen released to the air in the form of ammonia (361,000 tons) is about twice the total quantity of manure nitrogen applied to crops and almost three times the quantity that is not absorbed by the crops. The high level of nitrogen released as ammonia implies that there is a significant potential for increasing manure nitrogen available for crops. We assume that both excess nitrogen and ammonia emissions in the baseline exceed environmental standards; i.e., further increases in either one would result in unacceptable degradations in environmental quality.

Wide geographical differences in application rates reflect the relative abundance of cropland on which manure is applied. Lagoon operations, located primarily in the Mid-Atlantic, apply manure nitrogen at 9.2 times the agronomic rate, on average, compared with 5.5 times the agronomic rate for pit operations, located primarily in the Corn Belt regions. Livestock operations in the Corn Belt tend to be more integrated with crop production than elsewhere,

Table 3-1

Production, profits, emissions, and technology adoption under nitrogen application standard (NAS), ammonia nitrogen standard (ANS), and both

	Base	NAS		ANS		NAS+ANS	
Item			*% chg.*		*% chg.*		*% chg.*
Hogs (*mil. cwt.*)	119.10	117.96	-0.96	118.26	-0.70	115.61	-2.93
Total profits (*mil. $*)	3,700	3,487	-5.77	3,426	-7.40	3,187	-13.87
Hog enterprise profits (*mil. $*)	3,047	2,837	-6.89	2,805	-7.93	2,568	-15.72
Ammonia N - storage (*1,000 tons*)	327.5	325.3	-0.68	203.3	-37.91	198.8	-39.29
Ammonia N - field (*1,000 tons*)	33.8	34.9	3.38	53.1	57.16	52.1	54.15
Ammonia N - total (*1,000 tons*)	361.3	360.2	-0.30	256.4	-29.02	250.9	-30.55
Excess N - soil (*1,000 tons*)	137.7	0.0	-100.00	246.4	78.95	0.0	-100.00
Application rate (*factor of agronomic rate*)	7.3	1.0	-86.38	17.6	140.37	1.0	-86.38
Manure transport costs (*mil. $*)	0.0	205.6	-	0.0	0.00	231.9	-
Manure N on-farm (*1,000 tons*)	183.6	51.8	-71.81	284.6	55.02	42.3	-76.96
Manure N off-farm (*1,000 tons*)	0.0	127.7	-	0.0	0.00	235.7	-
Cover lagoon (*% farms, all farms*)	0.00	0.00	0.00	36.42	-	36.42	-
Inject manure (*% land, all farms*)	25.56	22.55	-11.78	37.66	47.33	37.46	46.54

so they generally have more cropland available on the farm for spreading manure (McBride and Key, 2003). For pit operations, the amount of excess nitrogen applied to land that is not absorbed by crops is about the same amount of nitrogen released to the air as ammonia. Lagoon operations, in contrast, release far more nitrogen into the air, primarily from the lagoon itself.

Nitrogen Application Standard

The CAFO rules require farmers to follow a nutrient management plan that eliminates excess applications of nitrogen. In our first scenario, we assume each hog operator must meet a nitrogen application standard. Farmers adjust their operations to meet this standard at least cost. CAFOs increase the share of their own land on which they apply manure, decrease the share of the land cultivated using chemical fertilizer, and increase shipments of manure off-farm to conform to this standard. As a result, total profits from the hog enterprise and the whole farm (accounting for crop production) decline about 6.9 percent and 5.8 percent (table 3-1, column 2).

Economic impacts are not distributed equally between the major manure handling technologies. Hog profits for farms using slurry systems decline 9.9 percent, versus 4.9 percent for farms using lagoon systems (table 3.2, column 2). Pit operations suffer larger losses because slurry manure contains more nitrogen than lagoon liquid. Even though pit farms tend to have more land available for spreading manure, the high nitrogen content of

Table 3-2

Production, profits, emissions, and technology adoption under nitrogen application standard (NAS), ammonia nitrogen standard (ANS), and both, by storage technology

	Base	NAS		ANS		NAS+ANS	
Item			*% chg.*		*% chg.*		*% chg.*
Lagoon operations							
Hogs (*mil. cwt.*)	70.76	70.52	-0.34	69.92	-1.18	68.50	-3.20
Total profits (*mil. $*)	2,019	1,929	-4.47	1,778	-11.95	1,686	-16.50
Hog enterprise profits (*mil. $*)	1,827	1,738	-4.88	1,586	-13.22	1,494	-18.26
Ammonia N - storage (*1,000 tons*)	255.0	254.1	-0.34	130.8	-48.69	128.2	-49.74
Ammonia N - field (*1,000 tons*)	14.8	14.7	-0.34	40.7	175.05	39.8	169.43
Ammonia N - total (*1,000 tons*)	269.8	268.8	-0.34	171.5	-36.43	168.0	-37.73
Excess N - soil (*1,000 tons*)	42.4	0.0	-100.00	136.3	221.64	0.0	-100.00
Application rate (*factor of agronomic rate*)	9.4	1.0	-89.31	25.4	171.11	1.0	-89.31
Cover lagoon (*% farms, lagoon farms*)	0.00	0.00	0.00	76.70	-	76.70	-
Pit operations							
Hogs (*mil. cwt.*)	48.34	47.44	-1.86	48.34	0.00	47.11	-2.54
Total profits (*mil. $*)	1,681	1,558	-7.33	1,648	-1.94	1,501	-10.71
Hog enterprise profits (*mil. $*)	1,220	1,099	-9.91	1,220	0.00	1,074	-11.91
Ammonia N - storage (*1,000 tons*)	72.5	71.2	-1.86	72.5	0.00	70.7	-2.54
Ammonia N - field (*1,000 tons*)	19.0	20.2	6.27	12.4	-34.54	12.3	-35.52
Ammonia N - total (*1,000 tons*)	91.5	91.4	-0.17	85.0	-7.17	82.9	-9.39
Excess N - soil (*1,000 tons*)	95.3	0.0	-100.00	110.2	15.53	0.0	-100.00
Application rate (*factor of agronomic rate*)	5.5	1.0	-81.88	10.7	93.27	1.0	-81.88
Inject manure (*% land, pit storage farms*)	48.67	42.93	-11.79	71.70	47.31	71.32	46.54

the slurry means they must still transport large amounts of manure off the farm, and incur high hauling costs.

The nitrogen application standard effectively eliminates excess nitrogen applied to the soil. The nutrient application standard also induces a 3.4-percent increase in the quantity of ammonia nitrogen emitted from fields (table 3-1, column 2), mainly because more land is receiving manure and because farmers that had been injecting slurry switch to surface application to use more manure and minimize off-farm transportation costs. However, the net effect of the policy on ammonia nitrogen emissions is very small, due mainly to the small decline in hog production. Hog production on each farm declines because of the increase in production costs relative to market prices for hogs (which are assumed constant). There is no real tradeoff between air quality and nitrogen available for crops because farmers were generally not taking steps to preserve the nutrient content of manure by preventing atmospheric losses in the first place. This suggests that large hog producers treat manure as a waste to be disposed of rather than a valuable source of nutrients.

Ammonia Nitrogen Limit

We also consider ammonia nitrogen limits based on the minimum levels obtainable employing currently available abatement technologies (lagoon covers and manure injection). For this policy simulation, manure nutrient application standards for protecting water quality are assumed not to exist. For pit operations, ammonia nitrogen emissions are constrained to 10 percent above the minimum obtainable if all manure is injected. For lagoon operations, ammonia emissions are constrained to 20 percent above what is obtainable if lagoons are covered. These limits were chosen so that costs to producers of meeting the emission standards are in the same range as under CAFO application standards and so that pit and lagoon operations face similar regulatory costs under the joint policy (next scenario). The constraint on ammonia emissions is in the form of a percentage reduction in net N emissions per pig.[1]

The ammonia nitrogen standard induces pit operations to switch from surface application to injection on some land, and induces some lagoon operations to cover their lagoons. The ammonia standard results in a 38-percent decline in ammonia emissions from manure storage facilities (the largest source of emissions) and a 57-percent increase in emission from fields, for a net decline in ammonia emissions of 29 percent (table 3-1, column 5). The increase in emissions from fields results because more lagoons are covered, which raises the nutrient content of the lagoon liquid applied to fields, resulting in greater nitrogen volatilization. The ammonia standard resulted in a 79-percent increase in excess nitrogen applied to soil—revealing an important tradeoff between water and air quality. For pit operations, the standard does not affect the profitability of the hog enterprise, so there is no hog production response (table 3-2). On the other hand, profits for operations with lagoons decline over 13 percent, resulting in a decline in production of about 1.2 percent, with no marketwide price effects accounted for.

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[1] Another option would have been to place a direct restriction on the entire farm. This would provide a different incentive to the farmer than the per-unit output restriction, and would likely result in a different outcome (Helfand, 1991). How different is an empirical question, but the direction of change would be the same.

Additional Simulations

To explore the tradeoffs between water and air emissions in more detail, we perform two more simulations. First, we examine how the levels of excess soil nitrogen and ammonia nitrogen vary for different nitrogen application standards applied to CAFOs (fig. 3-1). The application standard is incrementally tightened from 50 percent greater than the agronomic rate to full implementation (where manure must be applied at the agronomic rate for all crops). Reducing the allowable nitrogen application rate (moving from right to left along the x-axis) results in a large decrease in the excess nitrogen applied to the soil, but almost no change in the amount of ammonia released. Farms were not conserving manure nutrients prior to the CAFO regulations, so the nitrogen application standards had little impact on air emissions. With no ammonia limits, tightening the nitrogen application standards to improve water quality produces only a minimal tradeoff in terms of lower air quality.

A much different outcome occurs if hypothetical restrictions are placed only on ammonia emissions and CAFOs do not have to meet nutrient application standards (fig. 3-2). A significant tradeoff between water and air quality would occur with increasing restrictions on ammonia emissions and no restrictions on nutrient application rates. Moving toward full implementation of emissions-reducing technologies (lagoon covers and manure injection) causes a large increase in excess soil nitrogen. Since there is no incentive to apply at agronomic rates, and spreading on more land would increase costs, manure nutrients are overapplied.

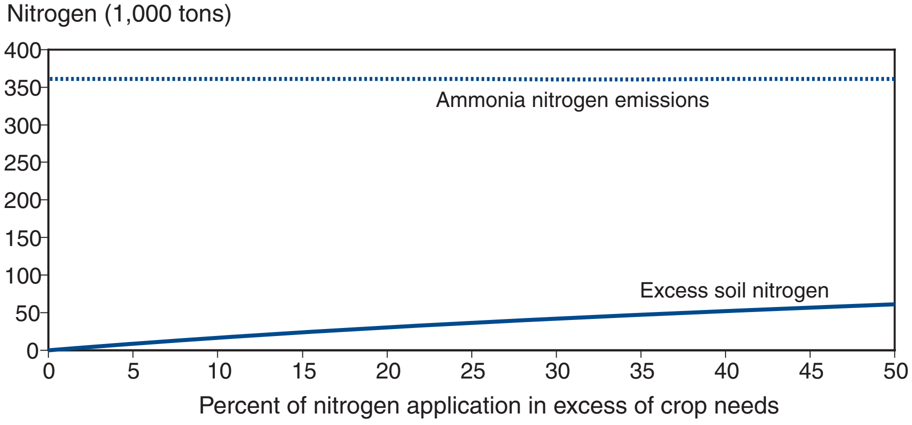
With no ammonia limits, tightening the nitrogen application standards to improve water quality produces only a minimal tradeoff in terms of lower air quality.

Coordinated (Air and Water) Environmental Policies

Relative to either of the single-medium policies, the joint policy is quite costly in terms of profits (column 7, tables 3-1 and 3-2). Hog operation and total farm profits decline by 15.7 percent and 13.9 percent relative to the base year. Production decreases about 3 percent. However, this policy

Figure 3-1

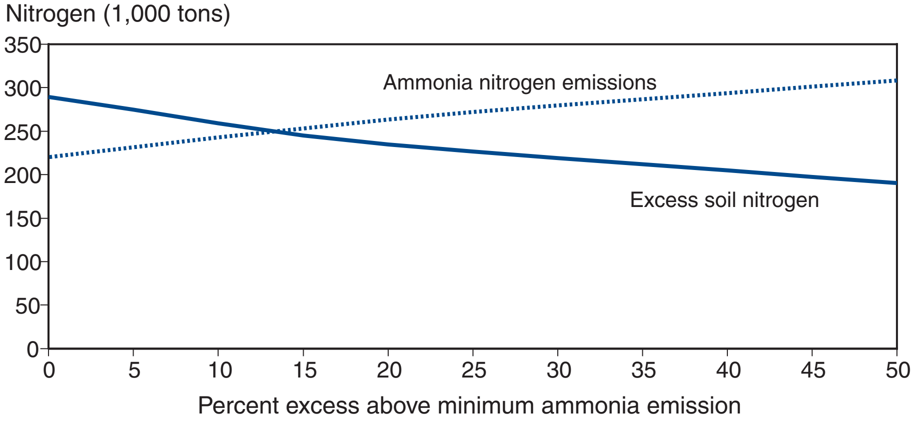
Tradeoff between ammonia nitrogen emissions and excess soil nitrogen under varying soil nitrogen standards



Note: Ammonia emitted to the atmosphere measured in terms of nitrogen.

Figure 3-2

Tradeoff between ammonia nitrogen emissions and excess soil nitrogen under varying ammonia nitrogen standards



Note: Minimum ammonia emission based on all operations adopting emissions-reducing management practices.

reduces ammonia nitrogen by about 30 percent relative to the levels under the CAFO regulations alone, and eliminates excess nutrient applications. Lagoon operations suffer the largest decline in profits, with hog profits declining 18.3 percent, compared with 11.9 percent for pit operations.

An indication that the individual policies could be in conflict is that the least-cost mix of technologies for addressing either an ammonia policy or a water policy is not the same as the mix of technologies that best meets a joint policy goal. Meeting the land application goal results in a decrease in the amount of manure that is injected, contrary to what would be required to meet the ammonia emission reduction goal. Similarly, meeting the ammonia reduction goal would result in a large increase in nitrogen applications that are in excess of crop needs.

This result implies that applying one policy after the other would result in higher costs than applying both simultaneously. To meet the ammonia emission goal after first implementing nitrogen application standards, manure injection on pit operations would have to increase 66 percent, rather than the 46 percent if the goals had been met simultaneously. This additional 20 percent of land requiring injection is the direct cost of implementing policies piecemeal rather than jointly. This land had been injected before the implementation of any policy, but shifted to surface application in response to the nutrient application regulations. To shift back to injection imposes a cost that would have been avoided if the policies had been implemented simultaneously. For lagoon operators, this conflict does not occur. Meeting the nutrient application standards first would not require any subsequent changes in storage technology to meet the coordinated policy goals (lagoons remain uncovered).

Farm-Level Decisions Have National Implications

This farm-level analysis highlights the economic and environmental tradeoffs that can occur with single-medium environmental policies as they are applied to hog farms. The two single-medium policies induce different responses. An ammonia emission standard alone would induce farmers to apply more excess nitrogen to the soil—a result likely to diminish water quality through increased nitrogen runoff and leaching. By itself, a nitrogen application standard to protect water quality does not have as dramatic an impact on ammonia emissions, but it does encourage an increase in surface application of manure, which increases potential ammonia losses from fields. Meeting both excess nitrogen and ammonia standards would be more costly than either single-medium policy.

Decisions made at the farm level are just the start of policy impacts. An operator who adopts waste management practices in response to regulatory requirements may also see an increase in production costs. Increased costs of production would, in turn, reduce the number of animals produced. When many hog farmers are affected by a policy change, new production levels may alter the market price of animal products and inputs (feedgrains, for example). Price changes springing from environmental regulations affect consumers and other sectors of the economy, and may cause animal producers to make further changes in their operations.

Chapter 4
National Effects of Coordinated Manure Management

Having examined the implications of addressing nitrogen concerns over water and air quality for one farm-level sector, we now take a larger view. The implications of coordinated (air and water) policies across regions and animal/crop sectors must account for interactions between crop and animal production and their subsequent economic and environmental impacts. Here, potential changes in commodity prices and shifts in production among regions are estimated assuming (1) adoption of land application standards for manure generated on concentrated animal feeding operations (CAFOs) and/or (2) reductions in nitrogen emissions to air from manure generated on all animal feeding operations (AFOs). Some consequences of national policy can only be viewed at this scale of analysis. Tradeoffs are not limited to the farm, but extend to regions and consumers. Market adjustments can produce contrary outcomes, even without the complication of conflicting single-medium policies.

At any level of analysis, adjustments to environmental policies entail increased costs to the producer. The magnitude of this increase depends on a number of factors, including the amount of manure transported for application, the availability of cropland for applying manure nutrients, the willingness of crop producers to substitute manure nutrients for commercial fertilizer, and regional heterogeneity in crop and animal production. Again, we consider current manure spreading regulations both independent of and in coordination with potential ammonia emission regulations across regions and sectors.[1] Specifically, we assess the environmental and economic implications of:

(1) Impacts of the 2003 Clean Water Act regulations for the spreading of animal manure on cropland for CAFOs (*Water*);

(2) Hypothetical reductions in atmospheric nitrogen emissions from animal feeding operations by 10-40 percent in the absence of manure nutrient application standards (*Air10, Air20, Air30,* and *Air40*); and

(3) CAFO water quality regulations plus AFO nitrogen emission regulations (10-40 percent reductions) in each region (*WaterAir10, WaterAir20, WaterAir30,* and *WaterAir40*).

We are looking for tradeoffs associated with implementing policies piecemeal rather than jointly, and indications that the different environmental goals (air quality vs. water quality) move the animal sector along different adjustment paths. Hence, we look at ammonia restrictions in the absence and presence of existing CAFO regulations for the protection of surface-water quality.

Simulating Coordinated Environmental Policies

We use the U.S. Regional Agricultural Sector Model (see Appendix B, web only) to assess secondary price and quantity effects between crop and animal

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[1] Here, though, we evaluate both nitrogen and phosphorus application standards. Because each region in the model is large, there is sufficient land to assimilate manure nitrogen in the baseline, meaning there is no overapplication. A nitrogen standard alone would result in no change in the model results.

production (USMP; House et al., 1999) at the national and regional levels (fig. 4-1). We simulate restrictions on manure nutrient use on cropland and on nitrogen emissions from animal production.[2] The model estimates nitrogen emissions to the atmosphere, which allows us to constrain ammonia emissions directly. This model has also been used in previous analyses of the Clean Water Act (Ribaudo et al., 2003; Kaplan et al., 2004).

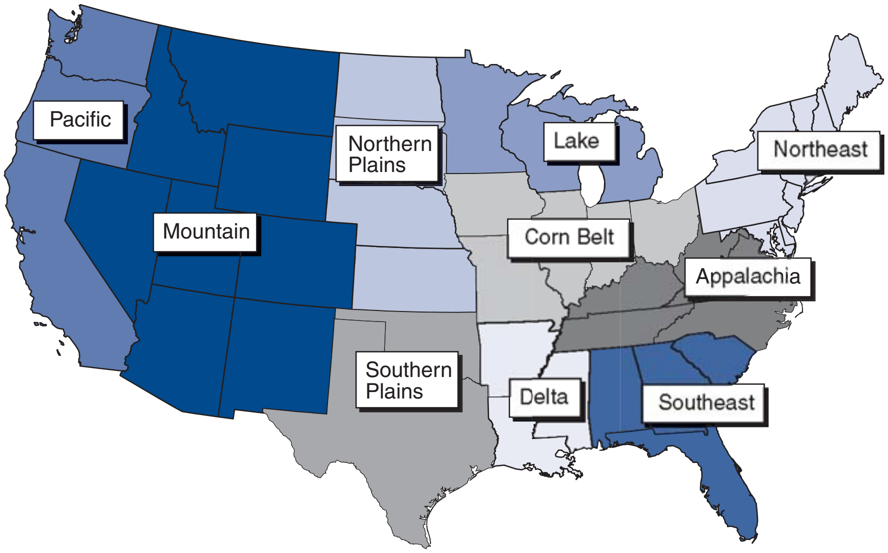
Various crop rotation, tillage, production and technology adjustments can be made to meet the nitrogen application or ammonia emission constraints. The composition of cropping or animal production could change to alter the amount of manure nutrients demanded or supplied. Storage, handling, or application technologies can reduce ammonia emissions or alter the nitrogen content of manure. Our model selects the optimal combination of technology, crop, and animal changes across the sectors and regions in order to minimize the net cost to society of meeting the different environmental policies. This includes changes in net returns for producers and changes in consumer surplus for purchasers of agricultural products. Storage, handling, and application technologies available in the model for meeting the CAFO nutrient standards and for reducing AFO emissions of nitrogen are consistent with those in the farm-level analysis.[3] We also consider treatment of poultry litter with aluminum sulfate (alum) to reduce nitrogen storage losses and to decrease the bioavailability[4] of phosphorus. Our baseline for comparison (*Base*) uses the USDA 2010 baseline projections for prices and production (USDA, WAOB, 2003) (table 4-1).

What Might We Expect?

CAFOs represent 4.5 percent U.S. feeding operations, but the quantity of manure generated by these facilities exceeds 200 million tons—more than 47 percent of the U.S. total (table 4-2). While the Corn Belt has the most AFOs and CAFOs and generates the most manure, the concentration of

Figure 4-1

USDA farm production regions



Source: Economic Research Service, USDA.

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[2] Manure generation is calculated according to Kellogg et al. (2000); crop nutrient demands by region are calculated using the Environmental Policy Integrated Climate Model (EPIC; Mitchell et al., 1998).

[3] We assume a crop producer willingness to accept manure of 30 percent, meaning that approximately 30 percent of available cropland in each region will utilize manure nutrients (USDA, ERS, 2003b). Alternative levels of manure utilization have been considered, but are not included here.

[4] Bioavailability of phosphorus refers to the amount of phosphorus in runoff that is available for aquatic and terrestrial plant growth.

Table 4-1

Policy scenarios for simulation analysis

Scenario	Manure nutrient spreading standards for CAFOs	Reduction in nitrogen emissions for AFOs
Base	No	No
Water	Yes	No
WaterAir10	Yes	10%
WaterAir20	Yes	20%
WaterAir30	Yes	30%
WaterAir40	Yes	40%
Air10	No	10%
Air20	No	20%
Air30	No	30%
Air40	No	40%

Table 4-2

Baseline for policy simulations

	AFOs						CAFOs		
							Operations	Manure	
Region	Operations	Total manure	Nitrogen runoff	Nitrogen leached	Nitrogen emissions	Phosphorus runoff	Share of total	Share of total	
		Million tons	*Million pounds*				*Percent*		*Tons/acre*
NE	31,350	39.10	32.60	0.17	189.61	5.46	1.59	16.45	0.45
LS	52,498	61.54	72.50	0.80	362.55	12.30	1.64	26.68	0.43
CB	71,252	83.75	87.60	1.02	517.85	25.98	3.18	39.49	0.34
NP	26,087	71.13	80.05	0.82	371.35	15.42	4.77	62.91	0.64
AP	22,776	78.32	120.49	2.01	571.36	34.81	7.46	65.95	2.88
SE	12,635	24.35	126.97	0.67	187.64	21.87	10.97	43.48	1.43
DS	12,252	19.66	33.33	0.34	137.95	9.86	7.48	39.44	0.44
SP	10,500	48.42	72.65	0.43	263.98	17.01	7.00	38.77	0.62
MT	7,780	33.52	80.45	0.09	215.23	14.69	8.43	70.22	0.89
PS	7,654	39.53	118.55	0.18	283.10	16.40	14.85	60.49	2.50
US	254,784	499.31	825.19	6.52	3,100.62	173.78	4.47	47.44	0.72

Northeast (NE) = CT, DE, MA, MD, ME, NH, NJ, NY, PN, RI, VT; Lake States (LS) = MI, MN, WI; Corn Belt (CB) = IA, IL, IN, MO, OH; Northern Plains (NP) = KS, ND, NE, SD; Appalachia (AP) = KY, NC, TN, VA, WV; Southeast (SE) = AL, FL, GA, SC; Delta States (DS) = AR, LA, MS; Southern Plains (SP) = OK, TX; Mountain (MT) = AZ, CO, ID, MT, NM, NV, UT, WY; Pacific States (PS) = CA, OR, WA).

CAFO manure per cropland acre is greatest in the Appalachia, Southeast, and Pacific regions. Therefore, we would expect land application standards for CAFO manure nutrients to result in greater production adjustments in these relatively land-scarce regions. On the other hand, because all animal feeding operations are subject to ammonia emission policies in our analysis, regions with large numbers of animals, such as the Corn Belt, are likely to be more affected by such policies.

What We Found

Higher production costs from meeting environmental standards result in changes to production levels, both animal production (fig. 4-2) and cropped acres (fig. 4-3). Animal production would fall under all scenarios, but to different degrees across sectors.[5] Dairy production would remain relatively unchanged (reductions of less than 1 percent), but reductions in beef

[5] We elected to focus on the results for a 10-percent reduction in ammonia emissions (*Water, WaterAir10, and Air10*). At higher levels of constraints on air emissions, it is likely that producers would consider many alternative technologies, which are not feasible to model at this point.

Figure 4-2

Changes in animal production by policy

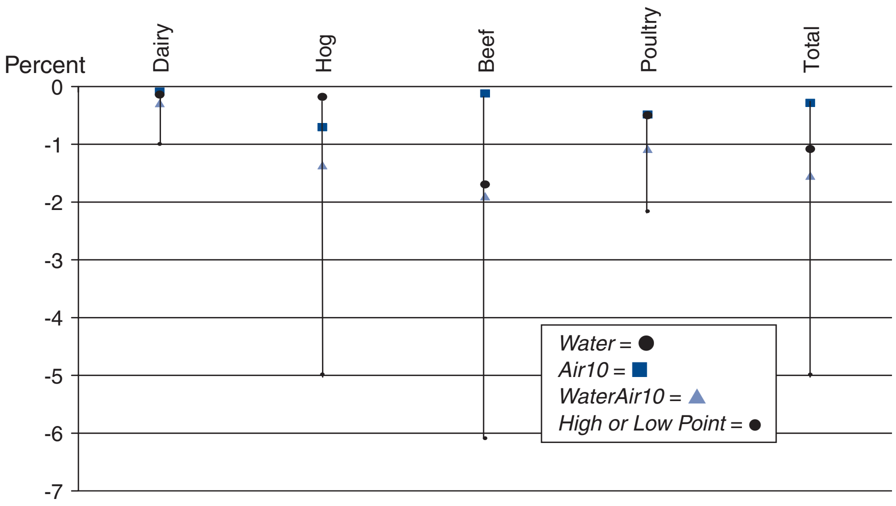
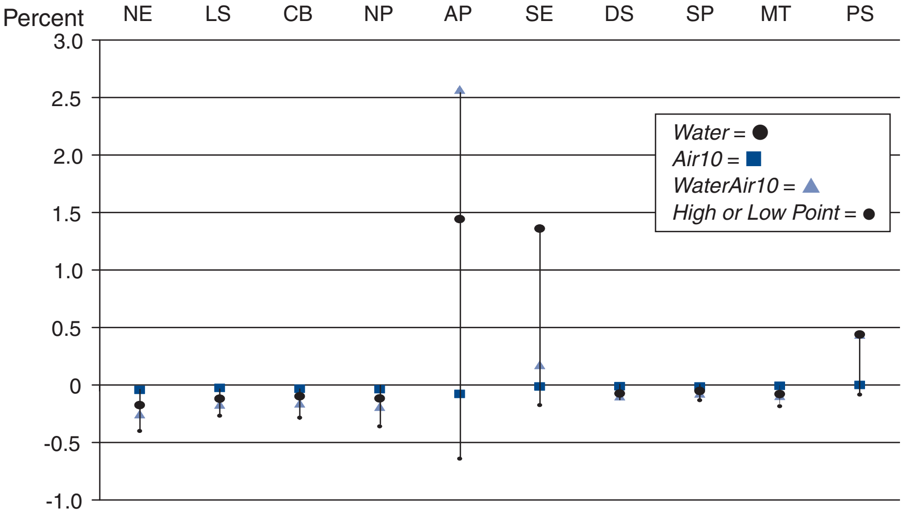


Figure 4-3

Change in cropped acres by region and policy



Northeast (NE) = CT, DE, MA, MD, ME, NH, NJ, NY, PN, RI, VT; Lake States (LS) = MI, MN, WI; Corn Belt (CB) = IA, IL, IN, MO, OH; Northern Plains (NP) = KS, ND, NE, SD; Appalachia (AP) = KY, NC, TN, VA, WV; Southeast (SE) = AL, FL, GA, SC; Delta States (DS) = AR, LA, MS; Southern Plains (SP) = OK, TX; Mountain (MT) = AZ, CO, ID, MT, NM, NV, UT, WY; Pacific States (PS) = CA, OR, WA).

production would range from 0.1 percent (*Air10*) to 6.1 percent (*Air40*). Hog production would also exhibit a wide range of production changes.

Beef and hogs exhibit greater reductions because the cost of meeting some environmental constraints are higher. Many hog CAFOs are in regions with limited land for spreading manure (such as Appalachia), and would require expensive emission abatement technologies (covering lagoons). Much of feedlot beef production is in regions where crop demand for nutrients would be relatively low (such as the Southern Plains); under a nutrient application standard, adjustment costs are high. On the other hand, beef producers could meet the ammonia emission constraint-only scenarios (*Air10* through *Air40*) at relatively low cost. The combined scenarios (*WaterAir10* through *WaterAir40*) would be the most costly, primarily because of the high transportation costs borne by CAFOs to meet the land application requirements when atmospheric emissions are constrained, increasing the nitrogen content of manure.

Dairy CAFOs generally have more land available for spreading, which keeps hauling costs down. The ammonia abatement measures for poultry are generally less costly than for other sectors. In addition, poultry litter has a higher nutrient value-to-weight ratio, so it would be less costly to haul.

At greater reductions in air emissions, the combined scenario (e.g., *WaterAir40*) can have a smaller impact on costs in all animal sectors than the air-only scenario (e.g., *Air40*) because the increased nutrient value of manure would increase the amount AFOs receive for their manure from crop producers, mitigating land application costs (crop producers are assumed to pay for manure).

Under two scenarios (*Water* and *WaterAir10*), the incentive to increase cropped acres where the CAFO manure application standard is most binding (Appalachia, Southeast, and Pacific) boosts cropped acres by 0.5 to 2.5 percent (fig. 4-3). For all other scenarios, cropped acres would fall as demand for feedgrain declines with decreasing animal production.

Technology Adjustments

Technology adoption would be influenced by the policy requirements and the relative costs of the management practices, determined by factors such as mix of animals, dominant production technologies, and cropland available for spreading manure. Consequently, total regional expenditures on practices for meeting environmental goals would adjust after simulated adjustments in production levels have taken place (table 4-3). Under the *Water* scenario, where only the CAFO regulations for protecting water quality are simulated, CAFOs would develop and implement nutrient management plans that minimize the cost of spreading manure. Hauling manure to cropland would be the predominant cost. If restrictions are placed on ammonia emissions from animal feeding operations, producers would begin using alum, incorporating/injecting manure, and covering their lagoons. The costs of these alternative storage, handling, treatment, and application technologies would increase as required reductions in ammonia emissions increase. Expenditures would be highest when both air and water quality goals have to be met (*WaterAir10-40*) because more actions to manage manure must be taken.

The producers' cost per animal unit for each scenario reveals the same relationship between the air and water scenarios as in the farm-level analysis. The sum of the costs of the CAFO regulation scenario (*Water*) and the hypothetical ammonia-only regulation scenarios (*Air*) would be less than the cost of the joint policy scenarios (*WaterAir*) that achieve the same level of

Table 4-3

Net manure storage, handling, treatment, hauling, and application costs

Region[1]	*Water*	*WaterAir10*	*WaterAir20*	*WaterAir30*	*WaterAir40*	*Air10*	*Air20*	*Air30*	*Air40*
					$ million				
NE	9.28	40.40	46.62	53.12	59.52	2.51	5.58	20.53	36.22
LS	34.55	77.76	92.87	110.90	127.56	3.97	8.03	20.41	58.08
CB	52.33	138.30	161.11	193.86	212.70	8.77	21.43	73.79	142.73
NP	129.26	127.38	137.11	132.13	201.74	2.78	9.38	33.20	139.40
AP	6.08	34.73	57.79	95.40	161.42	8.20	18.80	37.54	71.58
SE	23.24	29.33	41.64	53.96	66.75	5.53	16.47	27.93	39.65
DS	13.70	25.71	33.28	41.74	55.50	5.12	13.82	23.02	34.73
SP	47.35	47.65	56.24	74.11	54.49	1.73	7.05	16.68	61.33
MT	96.99	97.14	97.10	99.32	92.66	1.36	3.14	5.44	5.57
PS	121.69	124.00	124.37	126.57	128.76	2.27	4.87	7.73	17.15
Total U.S. cost	534.46	742.39	848.12	981.11	1,161.10	42.23	108.56	266.27	606.42
U.S. cost per AU ($)	4.99	6.96	7.96	9.31	11.19	0.39	1.01	2.52	5.89

[1] Northeast (NE) = CT, DE, MA, MD, ME, NH, NJ, NY, PN, RI, VT; Lake States (LS) = MI, MN, WI; Corn Belt (CB) = IA, IL, IN, MO, OH; Northern Plains (NP) = KS, ND, NE, SD; Appalachia (AP) = KY, NC, TN, VA, WV; Southeast (SE) = AL, FL, GA, SC; Delta States (DS) = AR, LA, MS; Southern Plains (SP) = OK, TX; Mountain (MT) = AZ, CO, ID, MT, NM, NV, UT, WY; Pacific States (PS) = CA, OR, WA.

ammonia reduction. Again, this indicates that the policies are in conflict. The optimal economic adjustments to the different environmental policies would involve tradeoffs; i.e., strategies for addressing ammonia control may make nutrient standards for CAFOs more costly and vice versa.

Regional Shifts

Examining the pattern of geographic shifts in production following our policy simulations provides further evidence that addressing ammonia and water goals independently rather than jointly would impose additional costs on producers. These shifts result from many simultaneous economic forces, reflecting relative costs of meeting regulations, animal mix, and resource base. As expected, meeting two environmental goals rather than one would impose additional costs on the sector and would result in a larger reduction in production. The CAFO regulations alone could reduce production by about 1.2 million animal units (table 4-4). Simultaneously reducing ammonia losses by 20 percent could reduce production by an additional 650,000 animal units (a total loss of 1.85 million).

Most regions would follow this same pattern; production losses would be greatest when both environmental regulations are in place. However, in the Mountain, Appalachian, Northern Plains, and Pacific regions, production would be higher under the joint regulations than under the *Water* scenario. In these regions, the costs associated with closing operations and losing production that would have occurred under the *Water* scenario could be avoided if the water and ammonia regulations are implemented simultaneously rather than independently.

Table 4-4

Changes in regional production

Region[1]	*Base*[2]	*Water*	*WaterAir10*	*WaterAir20*	*Air10*	*Air20*
			Million AU			
NE	4.176	-0.004	-0.123	-0.144	0.015	-0.068
LA	7.847	-0.099	-0.302	-0.359	0.045	0.110
CB	16.874	-0.375	-1.550	-1.725	-0.137	-0.251
NP	19.461	-0.848	-0.549	-0.648	-0.121	-0.643
AP	14.284	-0.323	-0.164	-0.225	-0.101	0.079
SE	3.871	0.005	0.019	-0.013	-0.043	-0.033
DL	3.082	-0.020	-0.120	-0.151	-0.053	-0.046
SP	21.224	0.400	0.729	0.880	0.042	-0.141
MN	10.365	0.450	0.651	0.755	0.041	0.254
PA	7.149	-0.358	-0.262	-0.220	0.006	0.082
US	108.333	-1.172	-1.671	-1.850	-0.306	-0.657

[1] Northeast (NE) = CT, DE, MA, MD, ME, NH, NJ, NY, PN, RI, VT; Lake States (LS) = MI, MN, WI; Corn Belt (CB) = IA, IL, IN, MO, OH; Northern Plains (NP) = KS, ND, NE, SD; Appalachia (AP) = KY, NC, TN, VA, WV; Southeast (SE) = AL, FL, GA, SC; Delta States (DS) = AR, LA, MS; Southern Plains (SP) = OK, TX; Mountain (MT) = AZ, CO, ID, MT, NM, NV, UT, WY; Pacific States (PS) = CA, OR, WA).

[2] Baseline values are taken from 2010 USDA baseline projections (USDA, 2003).

Environmental Implications

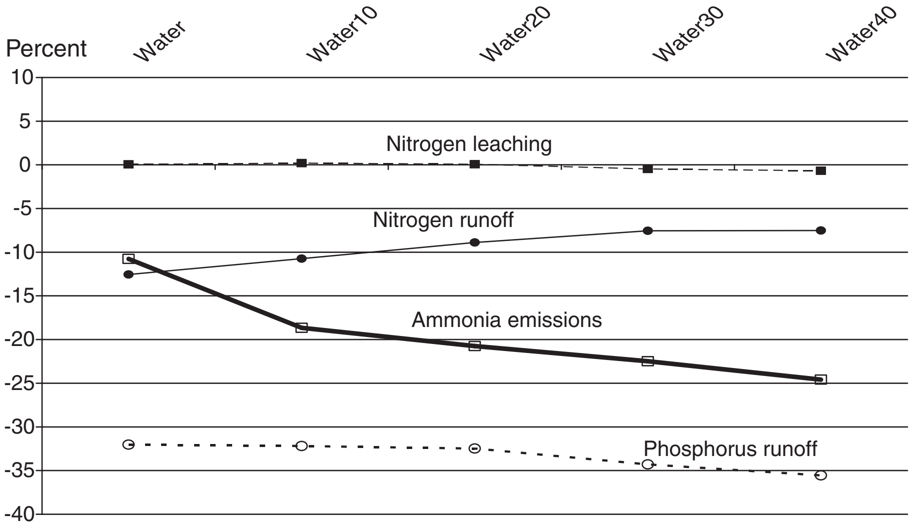
Environmental impacts result from changing manure management at the farm level, but also from changing the number of animals raised in each region. As AFOs adopt storage, handling, treatment, and application technologies to reduce ammonia emissions, the reductions in nitrogen runoff (from land application constraints) would gradually diminish. Runoff could even increase above baseline levels, supporting the findings of the farm-level analysis (fig. 4-4). With nutrient application standards in place on CAFOs (*Water*), nitrogen runoff would fall by about 12 percent. As restrictions on ammonia emissions are imposed, nitrogen runoff could increase. When emissions are reduced 40 percent, runoff would be about 7 percent lower than the baseline. Many of the environmental gains attributable to the CAFO regulations would disappear, primarily because non-CAFO operations are not subject to land application constraints. Manure spread on land from these operations would have higher nitrogen content due to technological changes adopted to reduce air emissions. Not restricting land application to agronomic rates would therefore increase nitrogen runoff. Again, policies addressing pollution to only one medium could increase emissions to a different medium. Without land application restrictions in place at all, reducing ammonia emissions would increase overall nitrogen runoff, even with fewer animals.[6]

Phosphorus runoff is a leading cause of surface-water eutrophication (overenrichment of nutrients causing algal blooms). While phosphorus is not part of the nitrogen cycle, manure contains high levels of this nutrient and meeting a nitrogen standard may still result in an overapplication of phosphorus (Ribaudo et al., 2003). This can degrade water resources so that they are unfit for swimming, boating, or fishing. Manure phosphorus, along with nitrogen, is a focus of the Clean Water Act's CAFO regulations. Under most simulated policies, phosphorus discharges would fall substantially (fig. 4-4). In the model, phosphorus applications are restricted under the CAFO regu-

[6] Some of the nitrogen applied to cropland leaches to ground water, which is an important source of drinking water in many areas. The policies examined would have little impact on nitrogen leaching nationally (see fig. 4-4).

Figure 4-4

Change from baseline in ammonia and nutrient losses to the environment, U.S.



lations when phosphorus is the limiting nutrient (posing greatest environmental threat). Also, one of the practices for reducing ammonia emissions—adding alum to poultry litter—would further limit the loss of phosphorus to water.

Economic Implications From Market Interactions

The farm-level analysis assumed constant prices, so the costs of meeting single-medium or joint policies would be borne fully by animal operations. However, animal production would be expected to fall under all scenarios (fig. 4-2) as producers adjust to increased production costs brought about by more intensive manure management. Such changes would likely lead to higher commodity prices, transferring some of the burden of higher costs to consumers (table 4-5). Crop producers would also be affected by what happens in the animal sector. Corn and soybeans are important feedgrains for animal production, and fewer animals being produced would dampen corn and soybean prices. In addition, policies to protect water quality could increase corn and soybean acres in some regions (receiving manure), which would also reduce prices.

Economic tradeoffs from a joint rather than uncoordinated policy approach can only be inferred from our results. The livestock sector would seemingly benefit from a joint policy versus uncoordinated policy. Reductions in net returns for any one of the joint policies would be less than for the *Water* scenario. Costs to the livestock sector from implementing only the CAFO regulations could have been reduced if hypothetical ammonia reductions had been required at the same time.

Table 4-5
Economic impacts and nitrogen reductions

	Water	*WaterAir10*	*WaterAir20*	*WaterAir30*	*WaterAir40*
	Change (million units)				
Nitrogen reductions (lbs. runoff, leaching, and air emissions)	1,169	1,553	1,599	1,653	1,779
Net returns to crop production ($)	449	328	307	267	196
Net returns to livestock production ($)	-897	-700	-724	-566	-268
Consumer surplus ($)	-402	-786	-876	-1,304	-2,053
Returns to agriculture and consumer surplus ($)	-850	-1,158	-1,293	-1,602	-2,125

Summary

A national manure management policy affecting a significant share of animal feeding operations would affect prices, producer net returns, and consumers. The environmental and economic impacts would vary greatly by region and animal type. The ability of the different sectors and regions to respond to the direct costs of water and air quality regulations depends on the size and structure of the agricultural operations, regional characteristics like available cropland, and responsiveness to price changes by the crop and animal sectors.

National results generally confirm farm-level results. Policies aimed at reducing ammonia emissions from animal manure would result in technological and production adjustments that could, in the aggregate, lead to increased discharge of nitrogen into surface and ground waters. This outcome is explored further for the Chesapeake Bay watershed.

Chapter 5

Impact of Spatial Factors on the Costs of Manure Management:

A Case Study of the Chesapeake Bay Watershed

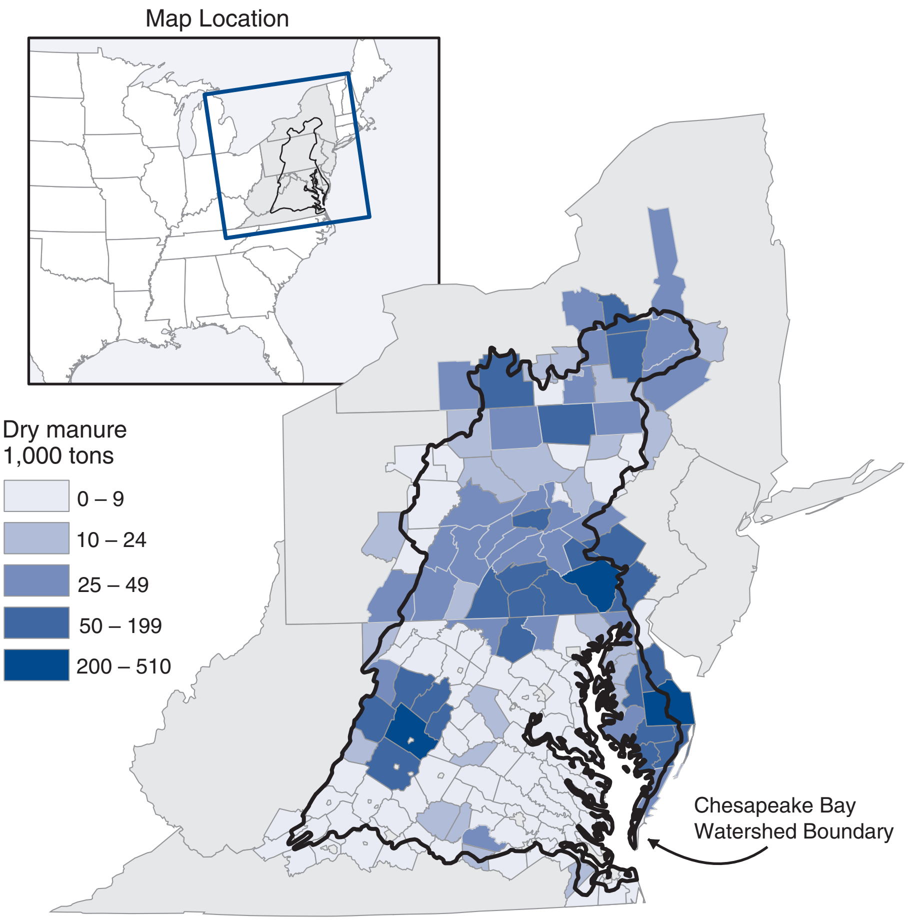
The costs associated with meeting USDA goals and U.S. EPA regulations for improved manure management depend not only on individual farm conditions and national markets, but on spatial considerations concerning the location of animal operations and cropland available for manure application. Where animal production is concentrated, producers may face competition for suitable land to apply manure, which can increase the cost of meeting application requirements by forcing manure to be hauled longer distances (Ribaudo et al., 2003). Implementing hypothetical ammonia emission controls on farms meeting nutrient standards could increase the competition for land by increasing the nutrient content of manure. Among U.S. areas where manure nutrient production exceeds the assimilative capacity of the land are several county clusters within the Chesapeake Bay watershed (Gollehon et al., 2001) (fig. 5-1). We present this case study to demonstrate how the costs of meeting Clean Water Act requirements might be affected if ammonia emission regulations are also imposed.

The Chesapeake Bay is among the largest and most biologically rich estuaries in the world. The declining health of this ecosystem in recent decades has prompted Federal and State initiatives to reduce nutrient loading from tributaries that drain the watershed. Nutrient discharges to waters in the region have resulted in eutrophication and related ecological shifts that harm wildlife and aquatic resources (Preston and Brakebill, 1999). Manure from confined animal operations has been identified as a primary source of both nutrient runoff to water bodies and local air emissions (Follett and Hatfield, 2001). A joint effort by watershed States to reduce nitrogen loadings is addressing all sources of nitrogen. The potential cost is high. The plan to upgrade 66 of Maryland's major sewage treatment plants will cost between $750 million and $1 billion, and would provide only a third of the nitrogen reductions needed for Maryland to meet its commitment (Maryland Department of Natural Resources, 2004).

The Chesapeake Bay watershed (CBW), spanning over 160 counties in 6 States, includes 66,600 farms with an estimated 8.5 million acres of land potentially available to receive manure. Approximately 15,900 farms in the CBW had confined animals in 1997, with an average daily inventory of about 1.6 billion pounds of feedlot beef, dairy, swine, and poultry (USDA, 1999). These animals produce roughly 93,000 tons of recoverable manure nitrogen, 44,000 tons of recoverable manure phosphorus, and 100,000 tons of ammonia-N annually. Even if confined animal operations fully utilized the crop and pasture land under their control for manure application, excess nutrients would remain. Applying manure at agronomic rates to meet water quality goals would require moving significant quantities of manure off animal producing farms.

Figure 5-1

Location of manure production in Chesapeake Bay watershed, 1997



Source: Economic Research Service, USDA.

The effect of alternative behavioral assumptions on the willingness of farmers to accept manure as a substitute for commercial fertilizer was examined in Ribaudo et al. (2003) for all confined animal operations in the CBW. Results from that study indicate that if farmland application is the primary disposal method, implementing nutrient management regulation poses significant challenges where animal production is concentrated. Only about half the manure produced CBW-wide can be used onfarm given current technologies and crop mixes. The feasibility of land application as a regional manure management strategy depends on the willingness of landowners to accept manure on farmland, the nutrient assimilative capacity of the regional cropland base, and the nutrient standard in effect. Ribaudo et al. estimated that more than 30 percent of CBW crop farms would need to accept manure in order to land-apply all the manure produced in the CBW at a rate based on the nitrogen needs of crops (under reasonable hauling distance assumptions).

The CBW case study uses a regional modeling framework designed to capture spatial considerations in manure production and land availability for manure spreading (see Appendix C, web only). The model and its results reflect a regional planning perspective in evaluating key cost determinants and alternative policy strategies at the watershed scale.

We assume that farms meeting nutrient application standards will apply manure at a rate based on a **nitrogen** standard for cropland and pastureland. Farms in locations with high phosphorus concentrations in the soil and runoff vulnerability may be required to base manure applications on a phosphorus standard, which generally decreases manure applied per acre (Ribaudo et al., 2003). While the effects of manure land application on phosphorus-limiting soils is an important concern in the Chesapeake Bay region, air emission controls interact primarily with manure-nitrogen concentrations. Thus, our focus is on changes in costs to meet a nitrogen standard.[1] We assume the willingness to accept manure by crop producers is 30 percent.

Determining the effect of emission control technologies on representative manure handling systems for the CBW required two steps. First, the quantities of total manure excreted were estimated from quantities of recoverable manure nitrogen available in the watershed (Aillery et al., 2005) and estimates of ammonia-N losses at the facility and field levels (appendix table D-1). This estimation process—from the field back to the animal—provides consistent estimates of manure nitrogen and ammonia emissions for a baseline situation. (Estimated values for selected systems commonly used in the CBW are provided in appendix table D-2.) In the second step, quantities of manure nitrogen available for plant use and changes in ammonia emissions were estimated from the animal to the field with the addition of emission control technologies by a manure-handling system. Nitrogen losses by system (see chapter 2) were converted to losses as a share of recoverable manure for direct inclusion in the model (appendix table D-3). An example of the estimation process to calculate nitrogen losses and crop availability under alternative emission control technologies is provided in appendix table D-4.

Land Application of Manure With Ammonia-N Reductions

We compare costs to the CBW animal sector of land-applying manure, and the water quality impacts, of four scenarios:

Case A—CAFOs meet nitrogen-based land application standards for water quality improvement, without consideration of ammonia-N emissions (current Clean Water Act policy);

Case B—CAFOs meet nitrogen-based land application standards for water quality improvement, with the addition of ammonia-N reducing technologies and practices;

Case C—All AFOs adopt ammonia-N emission controls for air quality improvements, while CAFOs continue to meet land application standards;

Case D—All AFOs adopt ammonia emission controls and meet land application standards.

For purposes of this analysis, methods of controlling ammonia emissions include the following:

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[1] Increasing the nitrogen content of manure by adopting emission controls does not increase the acreage needed for land application when meeting a phosphorus standard. In fact, the increased nitrogen in the manure reduces the supplemental nitrogen usually required.

- ***Incorporation/injection.*** Manure is incorporated or injected on 100 percent of acres receiving manure from poultry, dairy, and feedlot beef operations in the included farm set. We assume that lagoon liquid from dairies and feedlot beef operations is surface applied so that it is possible to inject the liquid with current technologies; swine lagoon waste is generally sprayed and is not typically incorporated. Under current conditions, incorporation is assumed to occur on 40 percent of CBW cropland for soil-nutrient retention and odor control, based on data from the ARMS hog and dairy surveys. This practice reduces ammonia emissions on acres currently treated. We assume the crop mix on land receiving manure does not change.
- ***Lagoon covers.*** Impervious lagoon covers are added to all dairy, swine, and feedlot beef operations using lagoon-based manure storage systems. The base model assumption is that no lagoons are covered.
- ***Alum.*** Alum is added to all poultry operations as an additive to the manure in the poultry house. The base model assumption is no alum use.

Case A—CAFO land application standards, with NO ammonia controls. The annual cost of meeting regulations for improved manure management to protect water quality is estimated to be $30 million[2] when only CAFOs meet land application standards (fig. 5-2). CAFOs account for roughly 19 percent of the total modeled manure in the CBW. The distribution of CAFO farms varies significantly across CBW counties, with the share of AUs on CAFO operations ranging from 0 (for about half the counties) to as high as 80 percent in some counties. The manure from non-CAFO farms is assumed to be applied on the source farm without the benefit of a nutrient management plan. Ammonia-N emissions from manure produced on all AFOs in the watershed total an estimated 100,000 tons, including 78,000 tons from animal production and manure storage facilities and 22,000 tons from field applications (fig. 5-3).

Case B—CAFO land application standards, with CAFO ammonia controls. The estimated cost to CAFOs for managing manure increases by $18 million relative to Case A (fig. 5-2). This reflects both the cost of implementing ammonia-controlling practices ($9 million) and the increased cost of applying manure according to a nutrient management plan ($9 million). Land application costs increase as a larger land area (more than doubled) is required to accommodate the nitrogen-enriched manure (fig. 5-4).

The addition of ammonia emission controls on CAFOs would reduce emissions by about 12,000 tons, relative to Case A, representing 12 percent of total animal emissions basinwide (fig. 5-3).

Case C—All AFO ammonia controls, with CAFO land application standards. Requiring all AFOs to control ammonia emissions would result in a CBW-wide reduction in emissions of 43 percent, 30,000 tons more than in Case B (fig. 5-3). The additional cost to implement air emission controls through expanded use of alum, lagoon covers, and incorporation on all AFOs, relative to Case A, is an estimated $41 million (fig. 5-2).

The threat of nitrogen runoff from CAFOs remains unchanged because the change in nitrogen content of manure is considered in the development of

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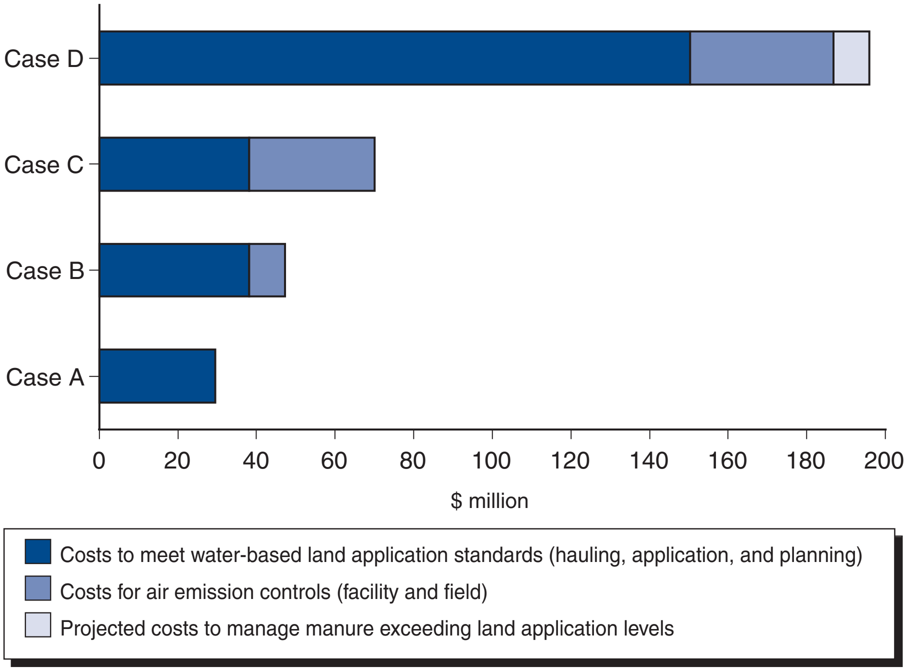
[2] Results here are very similar but not identical to those in Ribaudo et al., with the differences due to model and data improvements.

the nutrient management plans (fig. 5-3). However, the same cannot be said for non-CAFOs, which are not required to follow a nutrient management plan. Non-CAFOs are assumed to spread their manure on land near the production facility without a nutrient management plan, at an estimated cost of $80 million (not shown in fig. 5-2). If these operations do not adjust the amount of land receiving manure, the doubling of the nitrogen content of manure would increase the threat of runoff to the Bay.[3] Potential impacts on water quality would be an unintended consequence of the air quality policy if additional steps are not taken to address manure nutrient over-application.

Case D—All AFO ammonia controls, with AFO land application standards implemented simultaneously. A requirement that all AFOs follow a nutrient management plan in conjunction with meeting ammonia controls would likely limit the threat to water quality in the Bay while reducing ammonia emissions, but at an increased cost to producers. The decline in ammonia emissions is about 9,000 tons more than achieved under Case C (fig. 5-3). The lower field emissions under Case D reflect the overall reduction in field losses achieved by applying all manure at agronomic rates, in contrast to Case C where most of the manure (81 percent) is assumed to be applied at rates substantially above crop needs. The total estimated cost for

Figure 5-2

Annual costs of meeting nutrient application standards with alternative emission controls on CAFOs and AFOs, Chesapeake Bay Watershed*



Case A – CAFOs meet water standards, no ammonia controls
Case B – CAFOs meet water standards, CAFOs adopt ammonia-N controls
Case C – All AFOs adopt ammonia-N control, CAFOs meet water standards
Case D – All AFOs adopt ammonia-N controls, all AFOs meet water standards

*Assumes a nitrogen standard for manure land application with 30 percent of farmland accepting manure.

Source: Economic Research Service, USDA.

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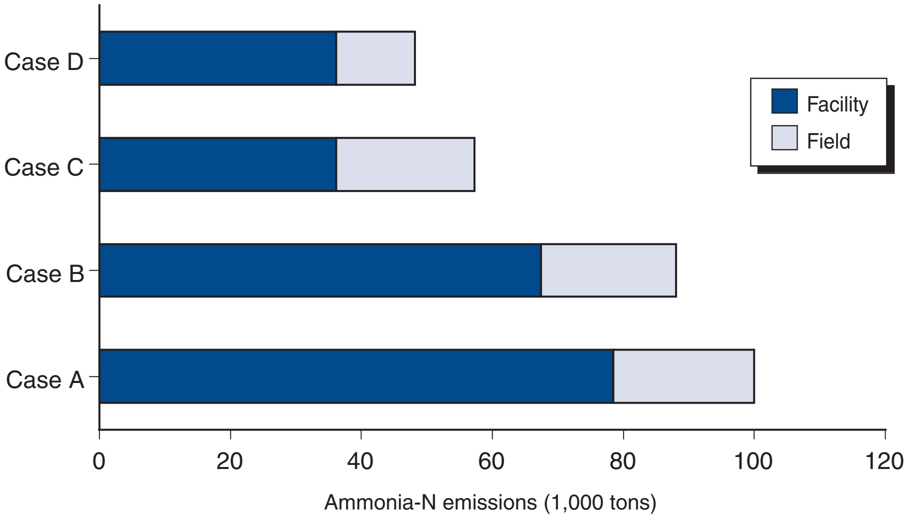
[3] The actual effect on water quality in the Bay will depend on the rate of nutrient loading from applied (and over-applied) manure, and the rate and location of nitrogen deposition from air emissions. The science behind these issues continues to evolve.

Figure 5-3

Ammonia-N emissions with alternative emission controls for CAFOs and AFOs, Chesapeake Bay Watershed*



Case A – CAFOs meet water standards, no ammonia controls
Case B – CAFOs meet water standards, CAFOs adopt ammonia-N controls
Case C – All AFOs adopt ammonia-N control, CAFOs meet water standards
Case D – All AFOs adopt ammonia-N controls, all AFOs meet water standards

*Assumes a nitrogen standard for manure land application with 30 percent of farmland accepting manure.

Source: Economic Research Service, USDA.

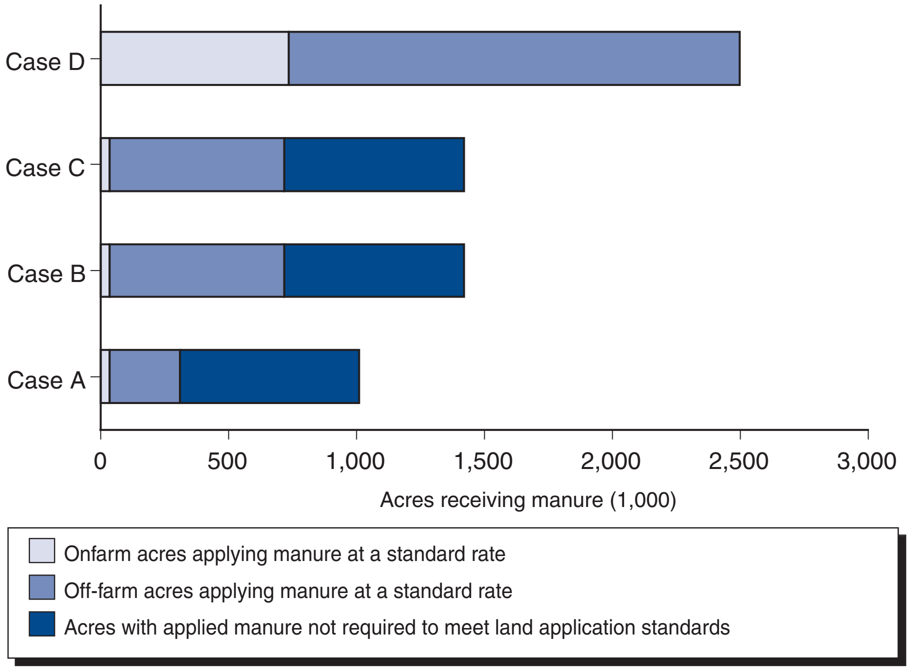
managing manure to meet ammonia control and land application requirements exceeds $186 million (fig. 5-2). Most of this reflects the implementation of nutrient management plans on all AFOs and a 75-percent increase in the number of acres receiving manure in an environment of intense competition for land (fig. 5-4). Land application costs on non-CAFO operations increase by an estimated $32 million.

An additional cost is for dealing with excess nitrogen for which no land is available within the CBW. Based on model simulations, the CBW has insufficient land to receive all manure when all AFOs are both controlling ammonia emissions and following a nutrient management plan, given an assumed farmer willingness to accept manure of 30 percent.

Various disposal strategies exist for handling this basinwide surplus, like increasing the willingness of crop farmers to accept manure (assumed to be 30 percent in this case study), increasing manure diverted to industrial processes, adjusting the diet of animals to reduce manure nutrients, reducing the number of animals, or transporting manure beyond the 100-mile limit assumed in the model. The latter option may be the least expensive. States have recognized the need to move manure extended distances to comply with nutrient regulations, and some offer a transportation subsidy. Delaware, for example, provides transportation assistance of $18 per ton (Rohrer, 2004). For illustrative purposes, if we assume that all the surplus manure in the model could be transported to land outside the CBW for application

Figure 5-4

Acres receiving manure from CAFOs and AFOs with alternative air emission controls, Chesapeake Bay Watershed*



Case A – CAFOs meet water standards, no ammonia controls
Case B – CAFOs meet water standards, CAFOs adopt ammonia-N controls
Case C – All AFOs adopt ammonia-N control, CAFOs meet water standards
Case D – All AFOs adopt ammonia-N controls, all AFOs meet water standards

*Assumes a nitrogen standard for manure land application with 30 percent of farmland accepting manure.

Source: Economic Research Service, USDA.

and/or other disposal at $18 per ton, disposal of all AFO manure produced in the CBW would exceed $9 million annually (fig. 5-2).

Reducing the region's animal units to a level where all manure could be land applied is a costly alternative. This approach would require as much as a 7-percent reduction in the number of animals in the CBW. With an average regional return per animal unit of $1,339[4], the annual costs of reducing the number of animals, plus land application of the manure produced, would total about $150 million at a willingness to accept of 30 percent.

Conclusions

Our analysis brings to light a key challenge in achieving air and water quality goals: strides to meet one goal may impede the other, as nitrogen is either applied to farmland via manure or emitted to the atmosphere. Animal producers in the Chesapeake Bay watershed required to meet regulations and guidelines for water quality protection face significant costs for managing manure. New air emission controls, if implemented, would increase costs to the animal sector. The higher nitrogen content of applied manure would pose a challenge to those producers with limited land,

[4] The value of production by animal unit is determined by using USDA baseline projections for 2010 (USDA. 2003). These projections are in turn processed through the USMP model (see Appendix B, web only) to convert animal production into animal units and to account for production cycles. For our purposes, we use gross value minus variable costs per AU to represent the opportunity cost of decreasing production.

requiring longer hauling distances to access adequate land. For other farmers needing nutrients, the nutrient-rich manure can be a resource.

Widely adopted ammonia emission controls could encourage overapplication of manure-nitrogen on non-CAFOs, to the detriment of water quality. Extending land application standards to non-CAFOs would substantially reduce nitrogen available for runoff, but substantially increase the total cost of air and water pollution abatement. The actual effect on water quality in the Bay will depend on nutrient loadings from applied (and overapplied) manure, and the deposition from airborne nitrogen.

Under current Federal regulations for land application of manure, the cost of air emission control reflects both the cost of control practices as well as the increased costs of meeting land application standards due to the higher nitrogen content of manure. Assessments that address practice implementation costs alone may substantially underestimate the full impact of air emissions control on the animal sector.

Cost impacts would be greatest where animal production is concentrated and manure quantities approach or exceed the assimilative capacity of the existing land base, increasing competition for land needed for manure spreading. Under these conditions, reliance on land application alone as a regional manure management solution may not be feasible. Other measures—such as increasing landowner willingness to accept manure, developing industrial applications for manure, subsidizing the long-range transport of manure out of the watershed, or even reducing animal stocks—may play a role in dealing with a regional surplus of manure nutrients.

Chapter 6

Summary and Implications for Policy and Research

Addressing the pollution problems generated by production activities can challenge policymakers concerned with economic efficiency when more than one environmental medium is affected by a single pollution source. This is true of many environmental issues. Coordinating policy so that all potential pollution issues are addressed simultaneously has been shown in the literature to be more efficient than dealing with each issue in an uncoordinated fashion, particularly when correcting one environmental problem worsens another (policies conflict). This report illustrates the tradeoffs in environmental quality by focusing on livestock and poultry production. Nitrogen in manure from animals on feeding operations can take a number of forms; reducing one form of nitrogen to protect one environmental medium can increase the amount of another form moving to a different medium.

Current environmental policies often fail to account for these interactions between media, as is the case with animal waste policies. Revised Clean Water Act regulations focus on managing land application of manure to reduce pollution of surface water. Restricting manure nutrient applications to agronomic rates can reduce manure's threat to water quality, but imposes costs on producers, primarily increased manure hauling costs. These costs can be reduced with manure handling and application strategies that promote the creation of ammonia and its loss to the atmosphere.

Ammonia emissions are a source of haze in the atmosphere, and a potential threat to human health. Recent lawsuits, court decisions, and consent agreements have induced some States to start regulating emissions under the Clean Air Act; the Comprehensive Environmental Response, Compensation and Liability Act; and State laws.

Tradeoffs Between Air and Water Quality Are Prevalent in Manure Nitrogen Management

Tradeoffs between air and water quality exist at the farm, regional, and national level. However, the magnitude varies, depending on baseline assumptions and scale of analysis. The farm-level analysis found that CAFO regulations for reducing nitrogen runoff had only a small impact on ammonia emissions in the hog sector. Hog operations had generally adopted practices that released ammonia to the atmosphere prior to the CAFO regulations (open lagoons and surface manure application), so there was little opportunity to further increase these emissions. Model results suggest that some operations that had been incorporating slurry (presumably for odor control) would start surface-applying manure in order to reduce the amount of land needed to receive manure, but this effect was relatively small. At the national level, implementing the CAFO water quality regulations could actually reduce ammonia emissions. Estimated reductions in animal numbers outweighed any small increase in per-unit ammonia emissions.

On the other hand, when we assumed hypothetical restrictions on ammonia emissions in the absence of the CAFO regulations, excess nitrogen applications (the cause of nitrogen losses to water) increased dramatically at the farm level, and to a lesser degree at the regional and national levels. Animal operations reduced ammonia emissions by covering lagoons and incorporating manure. Excess manure nitrogen applications that existed in the baseline increased as nitrogen in manure was conserved by preventing losses to the atmosphere and land applied to the same acres.

Uncoordinated Policies Impose Extra Costs on Farmers

CAFO regulations and the hypothetical ammonia reduction regulations provide much different incentives to farmers, and so encourage different management practices. Furthermore, neither set of management practices is the most economical for addressing a joint policy where both water quality and ammonia emission goals are set. Farms that adopt a set of practices to meet the CAFO water quality requirements might need to adopt a different set to meet both water and air requirements. The cost of changing practices could be avoided under a coordinated policy. A producer may even be reluctant to comply with new regulations for fear that the rules may change in the future. (Our models do not account for uncertainty or for the economic implications of “sunk” costs for adopting a set of waste-handling technologies and then having to adopt a new set.)

These differences in production costs have broader implications for the agricultural sector. Overall impacts for animal producers, crop producers, and consumers change considerably when hypothetical ammonia reduction goals are added to the CAFO regulations. Some of the regional shifts in production predicted for the CAFO regulations do not occur under a coordinated policy. This implies that some of the adjustment costs from a sequential (uncoordinated) implementation of regulations would have been avoided if they had been introduced together.

Unintended Consequences Can Lessen Environmental Gains

Should ammonia emission standards induce farmers to adopt manure management practices that reduce nitrogen emissions, the manure applied to land will have a higher nitrogen content. Depending on how the air quality regulations are applied, this can have two impacts on CAFOs and water quality. First, those farms identified as CAFOs may need to increase the amount of land they are spreading on to meet nutrient application standards if they are also required to reduce ammonia emissions. This can be particularly costly in a region where animal concentrations are high and cropland available for spreading manure is relatively scarce. In our analysis of the costs of spreading manure in the Chesapeake Bay watershed, nitrogen content of manure substantially increased when ammonia restrictions were introduced, increasing the costs of meeting nitrogen application standards. The higher cost of meeting water quality regulations might not be accounted for in an assessment of the cost of air quality regulations.

Second, a failure to coordinate water and air policies could lead to a loss of water quality benefits. If Clean Air Act or CERCLA requirements result in States requiring ammonia reductions on smaller farms as well as CAFOs, the water quality benefits of the CAFO regulations could be diluted by excess nutrient applications on the smaller farms. This was the case in both our regional and national analyses. Without regulations on spreading manure at agronomic rates, farms reducing ammonia emissions would be more likely to overapply manure, thus increasing nitrogen discharged to surrounding waters. It would be difficult to achieve ammonia emission reductions and still maintain water quality gains of the CAFO regulations if water quality regulations were not extended to smaller operations. Doing so would increase the costs to producers and consumers, but provide greater environmental improvements.

In our analyses, we have not assumed a relative value of air quality changes versus water quality changes. Monetary values associated with improved health and visibility from reduced ammonia emissions, and improved recreation and drinking water benefits from reduced nitrate runoff, have not been estimated at the national scale. These values would help policymakers respond appropriately to ammonia emissions and nitrogen runoff from animal feeding operations. For example, if water quality improvements are valued much less than air quality improvements, the "unintended consequence" of increased nitrogen runoff from an uncoordinated ammonia control policy may be of little concern.

Other Tradeoffs May Be Important

While we focus on the ammonia-nitrate tradeoffs, other interactions have a bearing on current environmental concerns. For example, animal operations are a primary source of the greenhouse gases methane and nitrous oxide. The former is not part of the nitrogen cycle. Its sources are the animal itself (enteric processes) and anaerobic storage. Nitrous oxide, which is part of the nitrogen cycle, is emitted primarily from fields where nitrogen is applied and from dry-waste-handling systems that have aerobic conditions. Commercial fertilizer is the primary source of agricultural nitrous oxide.

Policies that influence the number of animals, manure handling and storage systems, and the amount of nitrogen applied to land also influence greenhouse gas emissions. For example, if a nitrogen runoff-ammonia scenario reduces the number of beef cattle by 2 percent, methane emissions from beef cattle also decline 2 percent. Considering potential conflicts and synergies between policies aimed at visibility, health, water quality, and global climate change would be complex and costly, but could avoid unnecessary costs to the sector and to society as a whole.

Reducing Nitrogen at the Source Can Address Multiple Problems

Not creating pollution in the first place avoids the problems posed by conflicting policies. In the case of nitrogen and AFOs, increasing the efficiency of nutrient conversion to animal products can reduce nitrogen in waste. This would reduce the threats to air and water quality, and make addressing either or both by managing manure less costly. Major advances are being made in feed efficiency through animal genetics, herd management, phase feeding, and feed formulation.

Another onfarm option involves technology for separating manure into liquid and solid wastes. Each component has a different nutrient content and may be handled differently so that the overall cost for meeting water quality and air quality goals may be reduced.

Another option is to remove manure as quickly as possible from the animal facility and to use it as an input elsewhere. Manure is currently being used to produce commercial fertilizer and energy, and research is underway to identify other potential uses. Atmospheric emissions may be more easily controlled in an industrial setting where contact with air and water can be minimized, and emissions from a ventilation system can be filtered. Current cost and demand conditions have not yet spurred wide-scale development of such industrial options. However, as environmental concerns increase and local, State, and Federal governments deal with manure issues, the costs of manure management are also likely to rise, making industrial options for manure more viable.

This report takes a stylized approach to mass balance, focusing on one set of compounds (nitrogen) and two environmental media (surface water and air quality). A more complete analysis would consider atmospheric deposition of nitrogen (bringing in nitrogen emissions from other sources), greenhouse gases, and groundwater contamination. A full accounting of all the controls necessary to meet additional environmental issues would likely increase the cost to producers, but the magnitude would depend on the interactions between the different pollutant flows, and the degree to which manure handling technologies can address multiple problems. However, the essential link between production and environmental quality, and the tradeoffs between different policy approaches, would likely be similar to those suggested by these results.

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Appendix A
Modeling the Farm Level

Linear Program To Calculate Dual Values

Positive mathematical programming (PMP) is used to calibrate the farm-level model to base year data without having to add constraints that cannot be justified by economic theory. PMP takes advantage of the fact that it is easier to collect information about outputs and inputs at the farm level than information about costs. The observed output and input levels result from a complicated decision process based in part on a cost function that is known to the farmer but difficult or impossible to observe directly. Some costs—perhaps associated with the environment, risk, or technology—may be hidden to the researcher even when a detailed survey instrument is available. PMP incorporates information about unobservable costs by using a quadratic cost function that approximates the true underlying cost function.

There are three steps to the PMP calibration (Howitt, 1995). In the first step, a constrained linear programming model is used to derive dual values associated with the "calibration constraints." In the second step, the dual values are used to parameterize a calibrated quadratic objective function. In the third step, the calibrated model is used for economic analysis, by imposing environmental policy constraints.

In the first step, the linear objective is to maximize total net revenues:

(1) $$\max_{X1_{ir}} \sum_r \sum_i X1_{ir}(P_{ir} - C_{ir}),$$

where $X1_{ir}$ is the level of each output i in region r. The cost of producing each output is $C_{ir} = \sum_j A_{ijr}W_{jr}$, where A_{ij}r is the amount of input j required to produce a unit of output and W_{jr} is the input price. The optimization is subject to $j \times r$ resource constraints:

(2) $$\sum_i A_{ijr}X_{ir} \le \sum_i A_{ijr}X0_{ir}, \quad \forall\ j,r$$

where $X0_{ir}$ is the initial observed activity level, so that $\sum_i A_{ijr}X0_{ir}$ is the initial level of input j.

Inputs include land, capital, feeder pigs, feed corn, feed soy, and chemical nitrogen fertilizer. Outputs include hogs, corn, soybeans, and "other crops" (defined as the value of all other crops produced). All three crops can be produced under three fertilization regimes: (1) chemical fertilizer, (2) manure fertilizer applied to the surface, or (3) manure fertilizer injected into the soil. We use the extension of PMP developed by Röhm and Dabbert (2003) to allow for a greater policy response between crop fertilization regimes than between crops. To do so, we define three "variant activities" (chemical fertilizer, manure-spread, and manure-injected) for each crop and impose calibration constraints that distinguish between variant activities and the total activity for each crop. In practice, this approach results in greater substitution between, for example, corn fertilized by spreading manure and corn fertilized by injecting manure, than between corn and "other crop" production.

The calibration constraints for each activity are:

$$(3) \qquad X1_{ir} \le X0_{ir}(1+\varepsilon_1), \ \forall\, i,r \quad dual: \hat{\lambda}_{i,r}$$

where ε_1 is a small perturbation (see Howitt, 1995). Following Röhm and Dabbert, we include three additional calibration constraints corresponding to each set of variant activities. For corn activities, the additional calibration constraint is:

$$(4) \qquad \sum_{i \in cv} x1_{ir} \le \sum_{i \in cv} x0_{ir}(1+\varepsilon_2), \ \forall\, i,r \quad dual: \hat{\lambda}_{corn,r}$$

where *cv* is the set of corn variant activities: *cv* = {corn - chemical fertilizer, corn - spread manure, corn - injected manure}. There are two additional constraints analogous to equation 4 corresponding to soybean variant activities, sv, and other crops variant activities, *ov*.

From the 1998 ARMS survey and other sources, we observe prices P_{ir}, W_{ir}, the output levels $X0_{ir}$, and most of the input-output coefficients A_{ijr} (see Appendix tables A1-A4 for details). It would be desirable to include manure nitrogen as an input. However, we do not observe manure application rates, only the amount of land on which manure is applied.

Estimate Calibrated Quadratic Cost Function

In step 2 we define quadratic total variable costs as $\frac{1}{2}\hat{Q}_{ir}X_{ir}^{2}$, where $\hat{Q}_{ir} = (\hat{\lambda}_{ir} + \hat{\lambda}_{crop,r} + C_{ir})/X0_{ir}$, $\hat{\lambda}_{ir}$, are the estimated dual values associated with equation 3 the calibration constraints, and $\hat{\lambda}_{crop,r}$, are the estimated dual values associated with equation 4 the calibration constraints for each crop activity: crop $\in$ {*corn, soybean, other*}. Since equation 4 applies only to crops, $\hat{Q}_{ir} = (\hat{l}_{ir}+C_{ir})/X0_{ir}$ for *i=hogs*. The objective in step 2 is to maximize total net revenues:

$$(5) \qquad \max_{x2_{ir}} \sum_{r}\sum_{i} P_{ir}X2_{ir} - \frac{1}{2}\hat{Q}_{ir}X2_{ir}^{2}$$

subject to the resource constraints:

$$(6) \qquad \sum_{i} A_{ijr}X2_{ir} \le \sum_{i} A_{ijr}X0_{ir}, \ \forall\, j,r$$

Solution of the non-linear optimization problem defined by equations 5 and 6 results in the initial output levels $X0_{ir}$.

Estimate Activity Levels for Policy Scenarios Using Calibrated Cost Function

Having characterized the farmer's non-linear optimization problem that results in the observed initial values, the final step is to impose policy constraints and compare solutions to the initial values. The policies we consider are the CAFO nitrogen application constraint and a hypothetical ammonia emission constraint. Farms can respond to policy constraints by adjusting input and output levels. Pit storage operations can vary the amount of land on which they inject versus surface-apply manure slurry in order to alter the ammonia emitted to the air and the nutrients available to plants. Lagoon operations can cover their lagoons to reduce air ammonia emissions. EQIP payments can enter the farmer's decision problem by reducing costs of abiding by the CAFO rules.[1]

First we incorporate into the optimization a manure transportation cost that depends on how the manure is stored and handled. Prior to implementation of the CAFO manure application rules, farmers had little incentive to transport manure off-farm, and few did. According to the 1998 survey, fewer than 2 percent of farms transported manure off-farm. The CAFO manure application rules require farmers to apply manure at a rate that plants can absorb. In response to the CAFO rules, farmers without adequate cropland will need to transport some manure off-farm (Ribaudo et al., 2003).

For the policy analysis, the farmer's objective is:

$$(7) \quad \max_{x3_{ir}\,\mathrm{cov}_r} \sum_r \sum_i P3_{ir} X3_{ir} - \frac{1}{2}\hat{Q}_{ir} X3_{ir}^2 - (1 - EQIP)MTC_r - COV_r \cdot \kappa \cdot X3_{hogs,r}$$

where MTC_r is the cost of transporting manure off-farm, which is a function of technology choices that affect that nutrient availability to the crop—and consequently the amount of land on which the manure must be spread. Farms eligible for EQIP payments receive a share of the manure transportation costs and receive a per acre subsidy for land on which they apply manure at the agronomic rate. *EQIP* is defined as the share of manure transportation costs financed by EQIP. The per-acre EQIP subsidy is expressed as a per-unit subsidy and appears in the optimization as a higher price *P3*. The decision by lagoon farms to cover their lagoon is reflected in the binary choice variable COV_r (1 if covered, 0 otherwise). The cost of covering a lagoon is simply a cost κ per unit of hog output.

Manure transportation costs depend on the nutrient content of the manure (how it was stored), how it is applied (injected or spread), the availability of land on which to apply the manure, and what crops it is applied to. Estimates for the transportation costs per hundredweight of hog are based on a transportation cost model proposed by Fleming et al. (1998) (see Appendix table A-5 for details). Manure transportation costs equal the quantity of hogs used to produce manure transported off-farm, $hogs\_off_r$, multiplied by the manure transportation costs per hundredweight of hog. Manure transportation costs are distinguished for lagoon operations, which may or may not cover their lagoons:

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[1] We assume for this analysis that CAFOs do not receive EQIP payments.

(8) $$MTC_r = hogs\_off_r (COV_r * T_{cover,r} + (1 - COV_r) * T_{uncov,r}),$$

and for pit storage operations which may inject (versus surface-apply) manure into some portion of the land on which manure is applied:

(9) $$MTC_r = hogs\_off_r (INJ_r * T_{inject,r} + (1 - INJ_r) * T_{surf,r}),$$

where transportation costs per hundredweight of hog produced, $T_{e.r}$, depend on the manure storage and handling technology $e \in$ {covered, uncovered, surface-applied, injected}.

For lagoon operations, COV_r is a binary choice variable. For pit storage operations, INJ_r is the share of manure-applied cropland on which manure is injected:

(10) $$INJ_r = \sum_{i \in mi} A3_{i,land,r} X3_{i,r} \Big/ \sum_{i \in m} A3_{i,land,r} X3_{ir},$$

where *m* is the set of manure crop activities (corn, soybean and other crops, either spread or injected) and *mi* is the set of all cropping activities on which manure is injected.

The quantity of hogs that produce manure applied off-farm equals the total hogs produced minus the number of hogs required to produce the nitrogen from manure applied on-farm:

(11) $$hogs\_off_r = X3_{hogs,r} - \left(manrate_r \sum_{i \in m} X3_{ir} A_{i,ferN,r}\right)\left(\frac{COV_r}{NH_{cov}} + \frac{1 - COV_r}{NH_{uncov}}\right).$$

The number of hogs required to produce the nitrogen from manure applied on-farm equals the manure nitrogen used on-farm divided by the manure nitrogen available to crops per hundredweight of hogs, NH_e (which depends on the cover technology). The manure nitrogen used on-farm equals the pounds of manure nitrogen applied on-farm if it were applied at an agronomic rate $\sum_{i,m} X3_{ir} A_{i,fertN,r}$ (the rate at which chemical fertilizers are applied) multiplied by the factor $manrate_r$. From the survey we observe the average rate at which manure is applied to receiving land, but we do not know the rate applied to individual crops. Consequently, we assume that farmers apply manure at the same observed factor, $manrate_r$, above the agronomic rate for all crops.

There is an analogous equation for pit storage operations.

(12) $$hogs\_off_r = X3_{hogs,r} - \left(manrate_r \sum_{i \in m} X3_{ir} A_{i,fertN,r}\right)\left(\frac{INJ_r}{NH_{inject}} + \frac{1 - INJ_r}{NH_{surf}}\right)$$

Policy 1: Nitrogen application constraint. CAFO rules require a nutrient management plan that requires growers to apply manure nitrogen at or below the rate at which plants can absorb (the agronomic rate). This policy is imposed by constraining $manrate_r$ to be less than or equal to 1.

Policy 2: EQIP payments. The effect of EQIP payments can be modeled by adjusting the share of off-farm manure transportation costs borne by EQIP and by adjusting the per-unit subsidy for crops produced in accordance with CAFO application guidelines.

Policy 3: Ammonia nitrogen emission constraint. Hypothetical ammonia emissions regulations are modeled by imposing a limit, *Amlimit*, on the quantity of nitrogen from ammonia per-unit of hog produced. Nitrogen emissions per unit of hog produced, AmN_e, depend on manure storage and handling technologies. The ammonia emission constraint is:

$$(13) \qquad COV_r * AmN_{Cover} + (1 - COV_r) * AmN_{Uncover} \le Amlimit$$

for lagoon operations and:

$$(14) \qquad INJ_r * AmN_{Inject} + (1 - INJ_r) * AmN_{Surface} \le Amlimit$$

for pit storage operations. Note that the ammonia emission constraint does not depend on the quantity of manure transported off-farm. The application method (spread/inject) is assumed to be the same on-farm and off-farm.

Appendix table A-1

Initial production, $X0_{ir}$

Outputs	Units	Value	Source
Corn fertilizer	100 bushels	*	USDA ARMS Survey 1998
Corn manure surface	100 bushels	*	USDA ARMS Survey 1998
Corn manure inject	100 bushels	*	USDA ARMS Survey 1998
Soy fertilizer	100 bushels	*	USDA ARMS Survey 1998
Soy manure surface	100 bushels	*	USDA ARMS Survey 1998
Soy manure inject	100 bushels	*	USDA ARMS Survey 1998
Other fertilizer	$ (value of production)	*	USDA ARMS Survey 1998
Other manure surface	$ (value of production)	*	USDA ARMS Survey 1998
Other manure inject	$ (value of production)	*	USDA ARMS Survey 1998
Hogs	cwt	*	USDA ARMS Survey 1998

* Estimated mean value varies by region and size of operation.

Appendix table A-2

Output price, P_{ir}

Outputs	Units	Value	Source
Corn (all)	$/100 bushels	284	NASS - (average price 1997-99)
Soy (all)	$/100 bushels	700	NASS - (average price 1997-99)
Other (all)	-	1	-
Hogs	$/cwt	46.92	NASS -(average price 1997-99)

Appendix table A-3

Input price, W_{jr}

Inputs	Units	Value	Source
Land	$/acre	68.2	NASS Agricultural Land Values Final Estimates 1998, Statistical Bulletin Number 957 (national average) (use 7% of land value as rental rate)
Capital	$	1	(by definition)
Feeder pigs	$/cwt	80.25	NASS - (average price 1997-99)
Feed corn	$/100 bushels	284	NASS - (average price 1997-99)
Feed soy	$/100 bushels	700	NASS - (average price 1997-99)
Fertilizer - N	$/lb.	0.185	Ribaudo et al., 2003

Appendix table A-4

Resource use, A_{ijr}

Input-output	Units	Value	Source
Land-corn	acres/100 bushels	*	USDA ARMS Survey 1998
Land-soy	acres/100 bushels	*	USDA ARMS Survey 1998
Land-other	acres/$	*	USDA ARMS Survey 1998
Capital-corn	$/100 bushels	49.3	Foreman, 2001
Capital-soy	$/100 bushels	127	Foreman, and Livezey, 2002
Capital-other	Share of value	0.17	Same share as corn
Capital-hogs	$/CWT.	*	USDA ARMS Survey 1998
Feed corn-hogs	100 bushels /CWT.	*	USDA ARMS Survey 1998
Feed soy-hogs	100 bushels /CWT.	*	USDA ARMS Survey 1998
Feeder pigs-hogs	CWT/CWT	*	USDA ARMS Survey 1998
Fertilizer-N-corn	lbs./ 100 bushels	80.0	Kellogg et al., 2000.
Fertilizer-N-soy	lbs./ 100 bushels	236.7	Kellogg et al., 2000.
Fertilizer-N-other	lbs./ $	0.282	Same rate as corn

* Estimated mean value varies by region and size of operation.

Appendix table A5

Manure off-farm transportation net costs by region and manure storage and handling technology, T_{re}

Manure storage /handling technology	Eastern Cornbelt	Western Cornbelt	Mid-Atlantic	South and West
	Dollars/cwt of hogs			
Lagoon				
Uncover	1.33	1.36	2.01	2.15
Cover	5.32	5.38	6.57	6.83
Pit				
Surface	1.20	1.25	2.29	2.53
Inject	1.61	1.66	2.82	3.08

Source: Estimated. Base manure handling costs from Fleming et al. 1998. Unit mile cost from USDA, NRCS, 2003 C*osts Associated with Development and Implementation of Comprehensive Nutrient Management Plans*. Lagoon cover costs from Massey, et al. *Agronomic and economic impacts of lagoon based swine operations complying with the proposed EPA zero discharge rule*.

Appendix table A-6

Nitrogen available to crops and nitrogen ammonia emissions by manure storage and handling technology

Manure storage/ handling techology	Soil nitrogen available to plants, $Npercwt_e$	Air ammonia emissions from house and storage	Air ammonia emissions from land application	Total air ammonia emissions, AmN_e
	Lbs/cwt			
Lagoon				
Uncover	1.53	7.21	0.42	7.62
Cover	5.07	2.69	1.39	4.08
Pit				
Surface	4.83	3.00	1.32	4.32
Inject	5.95	3.00	0.20	3.20

Source: US EPA *National Emission Inventory--Ammonia Emission from Animal Husbandry Operations*, 2004.

Appendix table A-7

EQIP payments per unit of output by crop and region

Crop	Uni	Eastern Cornbelt	Western Cornbelt	Mid-Atlantic	South and West
Corn	$/100 bu	8.87	8.28	53.00	49.70
Soybean	$/100 bu	27.44	24.44	85.62	86.92
Other	Share of value	0.05	0.11	0.13	0.17

Source: Estimated using EQIP program data, Farm Service Agency, USDA.

Appendix B
USMP Model

The USMP model accounts for production of major crops (corn, soybeans, sorghum, oats, barley, wheat, cotton, rice, hay, and silage) and confined animals (beef, dairy, swine, and poultry), comprising approximately 75 percent of crop production and more than 90 percent of livestock and poultry production in the United States. USMP is a comparative-static, spatial, and market equilibrium model that incorporates agricultural commodity, supply, demand, environmental impacts, and policy measures. The model permits agricultural sectors to adjust to nutrient standards for air and water by substituting across space, production activities, and cropping and tillage practices with varying input requirements.

Crop and animal production choices are linked to edge-of-field environmental variables using the Environmental Policy Integrated Climate Model (EPIC), which uses a daily time step to simulate weather, hydrology, soil temperature, erosion-sedimentation, nutrient cycling, tillage, crop management and growth, and pesticide movements to the field's edge (Mitchell et al., 1998). The transport of nutrients, pesticides, and sediment across the landscape is calibrated to USGS estimates of regional pollutant loads (Smith, Schwartz, and Alexander, 1997).

Estimates of CAFO and AFO spreading practices on hog operations taken from Ribaudo, Gollehon, and Agapoff (2003) allow us to account for prior land application of manure in the simulations. Accordingly, CAFOs are assumed to spread manure on the nearest 155 acres and the smaller AFOs are assumed to spread manure on the nearest 90 acres. While these numbers are not necessarily representative of the range of production conditions across the Nation, we feel that these are reasonable for initial estimates of the environmental effects of excess manure application at the Farm Production Region scale. The above levels provide a lower bound on the estimated costs from meeting nutrient standards since many livestock facilities have little or no land on which to spread manure (Kaplan, Johansson, and Peters, 2004). Given the acres currently receiving manure nutrients, we calculate the quantity of manure nutrients in excess of the crop requirements on those acres. These excess nutrients are subject to leaching, runoff, and volatilization, similar to commercial fertilizers.

Manure transportation costs are determined using the Fleming et al. (1998) formulation in conjunction with regional and species-specific cost coefficients from the literature (Borton et al., 1995; Pease et al., 2001). The costs to develop a nutrient management plan, and to test periodically for manure nutrient composition and soil nutrient content are also included using USDA estimates (USDA, NRCS, 2003). Current market values for commercial nitrogen and phosphorus are used to calculate the savings from substituting manure nutrients for commercial fertilizers. The costs of using manure nutrients (testing, transporting, and applying) as fertilizers are covered by the livestock sectors. The savings in forgone commercial nutrient purchases by cropping enterprises are included in the returns to crop production.

Appendix C
Modeling Manure Management in the Chesapeake Bay Watershed

Our model is designed to minimize the total regional costs of manure management, transport, and application for use on agricultural lands in the Chesapeake Bay Watershed (CBW), given the existing structure and scale of the animal industry, and the current manure storage technology. The regional specification captures the element of competition for a limited land base by modeling access to spreadable land, requiring adequate area for land application of manure produced, and computing the associated hauling costs. Technologies that limit ammonia-N emissions alter regional competition by changing the costs and manure nutrient content across manure systems and animal types. Explicit modeling of competition for land on which to spread manure is a central feature of the regional model that is not captured in existing farm-level models.

The model was developed to: (1) provide a mechanism to track manure and related nutrient flows within the basin, from farm to site application and use, (2) compute the regional costs of land-applying manure, given the manure movement dictated by the nutrient uptake, and (3) provide a framework for evaluating alternative technologies that limit ammonia-N emissions, given land-application rates to meet a water-quality standard.

The county serves as the primary modeling unit for the regional model. The county-level specification provides consistency with Census of Agriculture data and other data, while permitting differentiation of institutions and regulatory conditions across county and State political boundaries within the watershed. County and local data are used to capture heterogeneity in technologies and land-quality conditions across the region, though our model may not represent the conditions on any particular farm.

The model is designed to minimize the regional cost of applied manure, subject to total manure produced and the land available for manure applications. Total regional costs of applied manure include transporting the manure, applying it to the land, implementing a nutrient management plan, implementing ammonia-reducing technology, based on 1997 production numbers. The model allocates manure flows between source and destination counties in the watershed to minimize the costs of hauling and applying manure, selected treatment costs, and costs of nutrient management plan development, given constraints on ammonia emissions and nutrient application rates. For a more detailed description of the water-based model, see Appendix 4-A in Ribaudo et al. (2003) or the technical documentation in Aillery and Gollehon (2004).

Including Air Emissions in the Modeling Framework

The regional modeling framework developed for manure management and water-quality policy analysis was extended to consider air emission measures. Air emissions were incorporated into the modeling framework by (1) adjusting the manure-nutrient content, (2) including treatment costs, and (3) calculating levels of ammonia emissions.

Changes in manure N content were calculated based on manure-nutrient adjustments by species, type of manure-handling system, and ammonia reduction measures. Changes in the N content of manure impact both the level of manure-N excess that must be transferred off confined animal farms and the rate of applied manure under an N-standard. Thus, implementation of policies to address air emissions issues will affect costs to the animal sector of meeting water-quality regulations.

The costs of emission control policies reflect the individual treatment costs for the three ammonia-reducing technologies considered-alum, incorporation into the soil, and lagoon covers-weighted by the share of acreage by species and manure system type, and use shares by treatment. Emissions were calculated by treatment scenario at both the storage facility (pre-haul) and field levels, for both regulated and non-regulated farms. Facility emissions are exogenous to the model, based on total manure production allocated across manure storage systems. Field emissions on regulated farms are calculated based on endogenously derived values for total land-applied manure (net industrial uses and that exceeding land capacity) and rate of applied manure in receiving counties. Field emissions on non-regulated farms were calculated from that portion of manure not explicitly addressed in the model optimization.

Model Data

Three primary data sources form the basis of the CBW model data set: the 1997 Census of Agriculture and the National Land Cover Dataset from USGS form the basic model structure and the National Emission Inventory from EPA is the source of the ammonia-N emission values. Farm-level Census data were used to generate county-level measures of animal operations and animal-units, total manure production, surplus recoverable manure, manure-nutrient content, and potential assimilative capacity of the land for applied manure nutrients. The National Land Cover Dataset was used to define the spatial pattern of land available for manure spreading and to simulate the spatial distribution of livestock operations (Ribaudo et al., 2003).

Model data on ammonia-N emissions were developed from system loss values presented in EPA's National Emission Inventory (NEI). For each manure-handling system, ammonia-N loss and retention are reported for animal confinement area, manure storage area, and land application area, based on a mass-balance approach. Starting from an excreted level of nitrogen in the manure, each unit of nitrogen will be either lost to the atmosphere or applied to the land for crop use.[1] Ammonia losses were aggregated for CBW model use based on losses from animal confinement

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[1] This assumption ignores direct discharge to water and accidental spills, which are believed to be non-significant.

and manure storage areas (termed “facility” losses) and subsequent losses during field application (termed “field losses”). The coefficients for ammonia-N losses were then derived at the facility and field levels, with losses expressed as a share of manure nitrogen available to the crop (and not as a share of excreted levels).

The shares of ammonia-N losses were then mapped to recoverable manure nitrogen available for plant use from Kellogg et al., (2000) to estimate the ammonia-N losses at each stage of the manure handling system.[2] Excreted manure nitrogen levels were derived from this mapping procedure for 1997 animal stocks in the CBW. For scenarios evaluating alternative technologies to reduce ammonia-N emissions, the process operated in reverse. From the calculated excreted nitrogen quantities, revised facility and field losses were subtracted to estimate a revised level of nitrogen available for crop use relative to the values in Kellogg et al., which constitute the core of the model data.

Production Cost Data

The NRCS Cost and Capabilities Assessment was the primary source of cost data for nutrient management plan components (USDA, NRCS, 2003). Manure hauling and application charges were based on published literature (Pease et. al., 2001; Fleming et. al., 1998), supplemented with data from the NRCS Cost and Capabilities Assessment. Transportation charges reflect a base rate per wet ton (loading/unloading and application) and hauling cost per ton-mile, by hauling mode and distance interval. Application costs are incorporated within hauling charges for lagoon and slurry systems; an additional charge was included for dry manure application. Per-acre costs of manure incorporation/injection were based on an Iowa State Farm Survey (2001). The baseline values assume that 40 percent of cropland acres currently incorporate manure, derived from information obtained in the ARMS hog and dairy surveys.

Chemical fertilizer costs were based on reported 1997 NASS prices, based on representative fertilizer products for the northeast States (USDA, NASS 2001). Cost-savings for reduced field application costs (under an N-standard) of $5 per acre were from Fleming, 1998. Annual costs associated with improved manure management practices to reduce ammonia-N emissions were: alum–$26.77 per poultry animal unit (AU) plus the additional hauling costs from adding an additional 10 percent to the weight of the litter; lagoon covers–$0.72 per AU for biofilter covers and $5.76 per AU for impervious covers; and incorporation/injection–$6.00 per acre. For a detailed description of the cost data see Appendix 4-A in Ribaudo et al. (2003) or the technical documentation in Aillery and Gollehon (2004).

For these systems, the share of N lost in each stage of the manure system was derived using a mass-balance approach based on manure management systems described by EPA (detailed in Chapter 2). Implementation of manure management practices to reduce ammonia-N emissions affects air emissions at different stages in the system. Alum affects the emissions from confinement structures while lagoon covers affect emissions from manure storage systems. These practices, which reduce ammonia emissions at the facility level prior to field application, actually increase volatilization during

[2] The values in Kellogg et al. were derived from the Census of Agriculture and are the basis for manure estimates in the model.

land application with surface application methods due to the manure's higher nitrogen content and expanded acreage requirements.

Incorporation/injection is a manure management practice that reduces ammonia emissions at the field level only. Field treatments can be used in combination with facility reduction practices or alone. In general, reducing the losses of nitrogen to the atmosphere increases the nitrogen level of manure available for crop use, and net reductions in emissions need to consider interactive effects from a broader systems perspective. Appendix table D-3 presents the model's assumptions regarding the changes in ammonia emissions and changes in the nitrogen level of the manure available for crop use. Appendix table D-4 presents examples of derived facility and field emissions using the coefficients in Appendix table D-3 for the major CBW manure systems in Appendix table D-2.

Appendix D
Data and Computation Tables

Appendix table D1

Base representative systems and ammonia-N emissions for use in the CBW model, by animal type and manure system type

	Representative system		
Animal type	Lagoon	Slurry	Dry/litter
Dairy	Flush barn, surface applied	Pond storage, surface applied	Dry, solids system, surface applied
Feedlot beef	Flush barn, surface applied	Pond storage, surface applied	Dry, solids system, surface applied
Swine	Daily flush, surface irrigate	Deep pit, surface applied	Minor technology (used values for dry feedlot beef system)
Poultry	Not considered	Not considered	Broiler house, surface-applied litter
	Facility emissions coefficients (share of N available to the crop)		
Dairy	4.242	0.637	0.309
Feedlot beef	4.242	0.637	0.309
Swine	4.725	0.621	0.309
Poultry	n/a	n/a	0.417
	Field emissions coefficients (share of N available to the crop)		
Dairy	0.282	0.209	0.0205
Feedlot beef	0.282	0.209	0.0205
Swine	0.274	0.274	0.0205
Poultry	n/a	n/a	0.333

Appendix table D-2

Manure ammonia-N production and losses for selected animal types and manure management systems for the CBW, baseline scenario

Animal type	Example manure system	Excreted nitrogen	Facility loss as ammonia-N	Field loss as ammonia-N	Nitrogen available for plant use
	Pounds per AU				
Dairy	Dry/Litter	99.2	20.25	13.43	65.5
Feedlot beef	Slurry	85.8	29.61	9.72	46.5
Swine	Lagoon	248.5	195.74	11.35	41.4
Poultry	Dry/Litter	421.8	100.5	80.26	241.0

Appendix table D-3

Ammonia-N emission and manure nitrogen changes with evaluated manure system improvements for use in the CBW model, by animal type and manure system type

Animal type	Item	Lagoon	Slurry	Dry/litter
Manure Management System Change: Alum to poultry litter (coefficients expressed as a share of N available to the crop)				
Poultry	Facility emissions	n/a	n/a	-0.679
Poultry	Field emissions	n/a	n/a	0.213
Poultry	Applied manure nitrogen	n/a	n/a	0.2125
Manure Management System Change: Biofilter Lagoon Cover (coefficients expressed as a share of N available to the crop)				
Dairy, feedlot beef, and swine	Facility emissions	-0.264	n/a	n/a
Dairy, feedlot beef, and swine	Field emissions	0.979	n/a	n/a
Dairy, feedlot beef, and swine	Applied manure nitrogen	0.979	n/a	n/a
Manure Management System Change: Impervious Lagoon Cover (coefficients expressed as a share of N available to the crop)				
Dairy, feedlot beef, and swine	Facility emissions	-0.627	n/a	n/a
Dairy, feedlot beef, and swine	Field emissions	2.326	n/a	n/a
Dairy, feedlot beef, and swine	Applied manure nitrogen	2.326	n/a	n/a
Manure Management System Change: Incorporate/Inject Manure (coefficients expressed as a share of N available to the crop)				
Dairy and feedlot beef	Facility emissions	0.0	0.0	0.0
Dairy and feedlot beef	Field emissions	-0.75	-.80	-0.18
Dairy and feedlot beef	Applied manure nitrogen	0.212	0.233	0.06
Swine	Facility emissions	0.0	0.0	0.0
Swine	Field emissions	n/a	n/a	-0.18
Swine	Applied manure nitrogen	n/a	n/a	0.06

Appendix table D-4

Manure ammonia-N production and losses for selected animal types and manure management systems for the CBW, Ammonia-N reduction scenarios

Animal type	Example manure system	Scenario	Excreted nitrogen	Facility loss as ammonia-N	Field loss as ammonia-N	Nitrogen available for plant use
	Pounds per AU					
Poultry	Dry/litter	Alum	421.8	32.26	97.27	292.2
Swine	Lagoon	Impervious cover	248.5	73.01	37.74	152.2
Dairy	Dry/litter	Incorporation	99.2	20.25	11.02	68.0