Spatial Considerations in Air- and Water-Quality Tradeoffs for Animal Agriculture

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Key Words:
Regional optimization, geographic information systems, spatial data, manure management, confined animals, nutrient policies, water quality, air quality, Chesapeake Bay

Abstract:
Total and average per ton costs of land-applying manure demonstrate the importance of spatial factors on the potential effect of policy limits for water and air emissions. Per ton costs vary with the need to transport greater distances for land application, reflecting the spatial distribution of cropland and animal production. Costs are estimated with a regional modeling framework, applied to the Chesapeake Bay watershed that integrates GIS-based spatial data within an optimization framework.

Introduction

The spatial interdependence of farms and production resources is often an important consideration in evaluating the effect of environmental policies on the agricultural sector. Environmental regulations may have widely varying impacts by locales and subsectors of the farm economy due to spatial differences in resource endowments, farm structure, and enterprise type. Economic assessments often attempt to capture this variation through analysis of representative farms and enterprises. However, spatial interactions *across* farms—often ignored due to data and analytic limitations—can also be an important determinant of the nature and magnitude of regulatory impacts. Recent examinations of Federal policies for animal waste management suggest that spatial relationships in land and animal production have a significant bearing on sector costs and environmental tradeoffs.

The management of animal manure from livestock production facilities has emerged as an important public policy concern, with implications for future regulatory controls and resulting increases in producer costs. In 1999, the Environmental Protection Agency (EPA) and U.S. Department of Agriculture (USDA) issued joint guidelines for regulatory and voluntary measures to protect water quality and public health from animal-waste pollution. In 2003, EPA published new regulations affecting an estimated 15,500 concentrated animal feeding operations (CAFOs) (U.S. EPA, 2003). Meanwhile, USDA has a stated goal that all animal feeding operations (AFOs) develop and implement Comprehensive Nutrient Management Plans (CNMPs) to minimize potential water pollutant loadings from confined animal facilities and manure land application (USDA, 2000b). Nutrient standards that restrict applied manure nutrients to levels not exceeding crop needs are a central focus under both the USDA policies and EPA regulations for controlling nutrient movement to water supplies. Implementation of manure-nutrient standards effectively increases costs in regions with substantial concentrations of confined animal production. As policies will require that much of the manure move off the source farm, costs to the animal sector will depend on the availability of land resources, and the competition for land to spread manure among animal producers.

While Federal efforts have focused primarily on water quality, ammonia loss from animal waste is increasingly viewed as an air-quality concern. Confined animal operations are the largest source of ammonia emissions in the U.S. (Abt Associates, 2000). Volatilized nitrogen compounds escape into the air, creating odors and contributing to fine particulates (haze) and greenhouse gas emissions (National Research Council, 2003). Emissions occur at all phases of the manure production cycle, from animal discharge to manure storage and land application. In the case of some manure handling and storage technologies, ammonia air-emissions has served as a legitimate means of protecting water quality by reducing the concentration of manure-nitrogen requiring land application (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 the concentration of nitrogen in lagoon effluent and resulting acreage requirements for manure spreading.

There is growing recognition of the need for an integrated policy response that considers interactions across water- and air-quality impacts. Implementation of manure-nutrient standards to meet water-quality standards may impose significant costs in regions with substantial concentrations of confined animal production relative to land. Additional restrictions on air ammonia emissions would have the effect of increasing manure-nitrogen concentrations, further limiting applied manure per acre and compounding the need for expanded acreage to apply surplus manure. Understanding complementarities and tradeoffs will assist in devising manure management policies that maximize environmental benefits at lowest cost to the animal sector. This requires an analytic framework that captures spatial variation in both 1) manure-nutrients concentrations by animal species and system type, and 2) the location and density of land resources available for manure land application. Differences in the spatial relationship of animal production to cropland area underlie important regional variation in sector costs and environmental outcomes, with implications for policy design and implementation.

To evaluate the costs of manure management policies, a regional modeling framework was developed and applied to the Chesapeake Bay Watershed (CBW). The Chesapeake Bay is the focus of a major Federal/State restoration initiative to reduce nutrient loadings from tributaries that drain the watershed. 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). The CBW encompasses several multi-county areas where manure-nutrient production from animal operations exceeds the local capacity of agricultural land to utilize manure nutrients when applied at crop-based rates (Gollehon et al., 2001). In areas of high animal concentrations, farmers face significant competition for land to spread manure under new regulations that restrict the rate of applied manure nutrients.

Previous Economic Research Service (ERS) analysis has examined the effect of nutrient standards for water-quality control (Ribaudo et al., 2003) as well as air-emission controls (Aillery et al., 2005b) on animal sector costs at a watershed scale. This paper builds on the ERS program of research in three principle ways. First, the analysis provides a closer examination of complementarities and tradeoffs in environmental controls for water and air quality. The analysis tracks 1) excess manure-N managed for water quality and 2) ammonia-N emissions managed for air quality, and associated costs per unit N. Second, environmental and economic tradeoffs are examined at a sub-regional level. While the watershed spatial scale appropriately accounts for the regional distribution of animal operations competing for available land resources, selected multi-county regions highlight the effect of differing animal concentrations relative to land for manure spreading. Finally, the analysis considers increases in the willingness to accept manure (WTAM) by farmland managers, an important determinant of costs faced by animal producers required to transport excess manure off the farm (Ribaudo et al., 2003). We examine water and air-quality policies, independently and jointly, with alternative numbers of farms required to apply environmental controls and two levels of landowner WTAM, in assessing potential economic and air- and water-quality tradeoffs.

Regional modeling framework

The modeling framework features a regional, nonlinear, cost-minimization model of manure-nutrient production and distribution[1]. An overview of the modeling system, including supporting data development for the optimization model, is presented in figure 1. The model is designed to assess the regional costs of manure management, given the existing structure of the animal industry, manure-storage technologies, and manure disposal options prevailing in the late 1990s. Regional manure management costs in the model are defined to include the costs of nutrient management plan development, manure transport from source to field, manure field application, and manure air-quality control measures (cost savings due to potential fertilizer offsets were not considered in this application). The model allocates manure nutrients produced within the CBW to agricultural land for crop use in a manner that minimizes hauling and land application costs incurred by the regional animal sector[2]. Primary policy variables involve nutrient standards for applied manure, technology enhancements for manure storage and application, assumptions on landowner willingness to accept manure, and alternative manure disposal options.

The model was defined at a watershed spatial scale that includes portions of six States (Virginia, Maryland, Delaware, Pennsylvania, New York, and West Virginia) to account for the regional distribution of crop and pasture land as well as animal operations competing for available land resources. A watershed scale is appropriate to assess implications of Federal manure management policies, given the regional resource

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1 A full description of the modeling approach implemented by ERS is beyond the scope of this article. A technical documentation of the basic model may be found in Aillery et al. (2005a).

2 Changes in the profitability of animal production are not assessed, since output prices and substitution possibilities are not considered. As with any model, modeled costs may not reflect the actual costs faced by all animal operations in the region.

interactions and Federal role in water-quality protection. Within the region, counties serve as the primary modeling unit. The county scale permits differentiation in manure production, waste technologies, nutrient uptake, and regulatory conditions across county and State boundaries within the watershed.

Perhaps the most innovative feature of the model involves incorporation of functional expressions for manure hauling that integrate county-based data on manure production and GIS land coverages within an optimization framework. Drawing on the spatial distribution of manure sources relative to the density of land potentially available for manure spreading, GIS was used to create 'area-to-distance' functions for within-county and out-of-county manure allocations across the study region. These functions are the core of the model, linking manure hauling distance with the area needed for manure spreading, and implicitly capturing the inherent competition for land that exists among animal producers.

While the regional optimization model represents the core of the system, data development activities were essential in estimating spatial relationships driving the model. The model relies primarily on national data series from the U.S. Department of Agriculture (USDA) and U.S. Geological Survey (USGS) for key model parameters. Farm-level data from the 1997 Census of Agriculture (USDA, 1999) were used to calculate county-level measures of animal operations and animal-units, manure-nutrient production, and nutrient assimilative capacity of cropland. Farm-level measures of surplus recoverable manure nutrients (in excess of crop needs on the source farm) were summed to the county-level following procedures in Gollehon, et al. (2001) and Kellogg, et al. (2000). Land area available for manure application is based on the 1994 National Land Cover Dataset (NLCD), developed by the USGS (Homer et al., 2000). The NLCD is derived from 1992

Landsat thematic mapper imagery at 30-meter resolution, classified into 21 landuse categories. By combining the cropland and pasture land categories within a GIS, we were able to define the spatial pattern of land available for manure spreading in the study region. The Census and NLCD data ensure consistency across the watershed, while facilitating the potential for model updates and transferability to other U.S. watersheds. Additional supporting data used in deriving technology, cost, and emission coefficients representative of the CBW or Mid-Atlantic region were obtained from various sources, including the USDA's Natural Resources Conservation Service's (NRCS) Cost and Capabilities Assessment (USDA, 2003), the EPA's National Emission Inventory (USEPA 2004), the Agricultural Resource Management Survey (ARMS) (USDA, 2002; USDA, 2000a), published literature, and information provided by subject matter specialists within the government and universities.

For modeling purposes, several systems for each animal type were selected from EPA's National Emission Inventory (NEI) as representative of manure system types. 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 Aillery et al., 2005b). Ammonia losses were aggregated for CBW model use based on losses from animal confinement 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).

Policy Scenarios Examined

We present an analysis of manure land application in the CBW based on a regional modeling framework designed to capture spatial considerations in manure production and land availability for manure spreading. The model and its results reflect a regional planning perspective in evaluating key cost determinants and alternative policy strategies at the watershed scale. We apply the model to estimate the feasibility and cost of applying manure in the CBW with and without alternative technologies to limit ammonia-N emissions. We then compare the cost and manure-use distribution over selected emission technologies to assess cost-effectiveness and potential tradeoffs and joint benefits across air and water-quality control objectives. The number of animals and quantity of manure produced remained the same across all scenarios.

The analysis highlights potential interactions of manure management policies in the Chesapeake Bay watershed to address environmental objectives for water-quality and air emissions. The general approach involves a comparison of animal sector costs of applying manure under three broad policy cases:

A. Targeted animal farms meet (nitrogen-based) land application standards for water-quality improvement, without consideration of ammonia-N emissions;

B. Targeted animal farms meet land application standards and adopt ammonia-N emission controls simultaneously;

C. Targeted animal farms adopt ammonia-N emission controls for air-quality improvements, with only CAFOs meeting land application standards.

The number and nature of farms potentially included in efforts to control ammonia-N emissions is likely to be an important consideration in policy development. Accordingly, we focus mainly on the number of farms applying environmental controls. Five groupings of farms evaluated include: CAFOs only, and all CAFOs plus 25, 50, 75, and 100 percent of the remaining AFOs. The set of 'CAFO-only' farms, or those farms currently subject to Federal water standards for manure management under the Clean Water Act, represents about 20 percent of the animal units (AUs) in the CBW. The spatial distribution varies significantly across the counties within the watershed, with about half the counties having no CAFO operations to some counties with as many as 80 percent of AUs on CAFOs. The number of non-CAFO AFOs meeting land application standards will depend on participation under voluntary USDA guidelines and State-level requirements for manure-nutrient management.

For purposes of this analysis, we assume that farms meet nutrient application standards for land applied manure according to a nitrogen standard. (Farms in some locations with high soil-phosphorus concentrations and runoff vulnerability will be required to base manure applications on a phosphorus standard, which decreases manure applied per acre.) Scenario runs assume a willingness to accept manure (WTAM) on 30 percent of cropland and pastureland acreage. The willingness of crop producers to use manure is an important determinant of the cost of land-applying manure, particularly in a region where animal concentrations are high. National survey data suggest that the 30-percent WTAM assumption is a reasonable estimate, although additional research on this issue is needed (Ribaudo et al., 2003).

We consider three actions to limit ammonia emissions during the manure production and disposal cycle: alum added to poultry houses, impervious lagoon covers on storage facilities and incorporation/injection at the time of land application. The analysis does not impose an air quality standard; rather it requires groups of farms to install technology-based control measures that are representative of the suite of air control measures. Other management and technology-based measures may be available. Specifically, in this study we consider:

- *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.*
- *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.*
- *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 and thus possible to inject the liquid with current technologies; swine lagoon waste is generally sprayed and is not typically incorporated. Under baseline conditions, incorporation is assumed to occur on 40 percent of the cropland acres across farm groups. Currently done for soil-nutrient retention and odor control primarily, the practice has the effect of reducing baseline ammonia emissions on acres treated.*

Model Results

Findings of the analysis are organized in five sections. We first review the effects of policy scenarios on the quantity of manure nitrogen managed at a watershed scale. Manure nitrogen management is affected by water-quality policies that restrict applied manure per acre as well as air quality controls that increase manure-nutrient content. Second, we examine policy effects on ammonia-N emissions. Ammonia emissions are affected primarily by emission control treatments, although changes in acres receiving manure from water regulations may affect air emissions. Third, we consider total regional costs of manure management in the CBW. Regional costs include the cost of developing the nutrient management plan for water-quality control, the cost of air quality control practices, and the additional cost of manure hauling and land application due to water and air-quality provisions. Regional cost curves highlight the cost and potential for manure nitrogen entering the environment. Fourth, we review the change in regional costs per change in ton of manure N managed for air and/or water quality. The cost per ton provides insight into the assessment of relative costs per ton of nitrogen intercepted from entering either air and water resources. Finally, we assess selected subwatersheds to evaluate the importance of spatial variation in key policy variables.

1. Manure nitrogen managed for water quality improvement

Figure 2 shows the quantity of manure nitrogen available for land application and the share applied under a land application standard by policy scenario. The bar length indicates total quantity of manure nitrogen that is potentially addressed under each policy approach. When the focus is only water quality (Policy A), about 105,000 tons of manure N receives policy attention. When both air and water resources are included (Policy B and C), over 230,000 tons of manure N are available for land application.

The three shadings on each bar describe the disposition of the manure nitrogen. Nitrogen may be managed on the farm of production and applied according to agronomic standards (lightest shade). Excess manure may be moved off the farm of production and applied according to agronomic standards to other lands (medium shade). Otherwise, excess manure may be land-applied when the application rate is not controlled or allocated to industrial processes (dark shade). Under current Federal water quality regulations (Policy A) impacting only CAFOs (bottom bar), roughly 6 percent of total manure nitrogen produced in the watershed is land applied on the source farm and 20 percent is applied to other lands according to nutrient standards.

Within policy alternatives A and B, as farms are added (from CAFOs only to all AFOs) there is an increase in the total manure nitrogen applications meeting land application standards. The increase in manure nitrogen managed, moving from policy alternative A to B for a similar number of farms, is due to the air-quality control technologies retaining a greater share of nitrogen in the manure that is available for land application. When all AFOs adopt air control technologies, over 200,000 tons of manure nitrogen would be applied under land application standards. Manure with greater nitrogen levels requires more area for land application. The 'all AFO' alternative under Policy B requires a substantial increase in land area for spreading and the model failed to land-apply all the available manure in the watershed. Policy alternative C requires agronomic land application rates only for CAFOs, and thus the acreages are constant without regard to air quality issues. However, the increased nitrogen content from air quality controls under this policy without accompanying limits on land application could increase risk to water quality.

2. Ammonia-N Emissions

The length of the bar in Figure 3 describes the total ammonia emissions from animal operations in the CBW. The two shadings on each bar describe the ammonia emission levels from farms and fields where ammonia controls are in place and those without emission controls. The control measures considered in this analysis reduce, but do not eliminate atmospheric emissions, and ammonia emissions will continue even in cases where all farms adopt the representative technology-based control measures.

Ammonia emissions from all animal feeding operations in the Chesapeake Bay watershed total about 105,000 tons per year. Emissions from CAFOs alone comprise 24 percent of the total, mostly from facility emissions. In policy alternative A, which does not consider air emissions, some air emission are controlled because incorporating manure for odor and soil nutrient retention also reduces air emissions (Figure 3). Increasing the amount of emissions controlled reflects increases in acreage using incorporation to reduce the risk of water runoff as the number of targeted farms increases.

Policy alternative B achieves the lowest total emissions, as indicated by the shortest bars. This is because air emissions are considered jointly with land application standards. Expanding the number of farms with ammonia-N controls beyond CAFOs results in continued reductions in ammonia-N emissions (Figure 3). If the CAFOs and half the remaining AFOs adopted the combined ammonia-N controls in the model, a 22-percent reduction in ammonia-N emissions is projected, relative to CAFOs only. If all AFOs are targeted, a 45-percent decline in air emissions is forecast.

When ammonia emission controls are in place without considering the linkages to land application levels (as in Policy C), the total air emission levels are 5 to 10 percent greater, as shown by the longer bars in Policy C relative to Policy B (Figure 3). This relative reduction in the effectiveness of air-control practices is attributable to the spreading of manure with higher nitrogen content. Conventional land application techniques generally do not prevent the volatization of nitrogen from manure in the field.

3. Regional Costs

The total cost of managing manure nitrogen is illustrated in Figure 4. The quantity of manure nitrogen managed is based on the sum of excess manure nitrogen transferred off the animal farm and applied under land standards and the quantity of ammonia nitrogen controlled. Each cost curve represents a policy option applied to an alternative number of farms, with higher costs and greater nitrogen control associated with greater farm numbers.

Quantities of manure nitrogen managed are additive, with a ton of excess manure nitrogen applied at agronomic rates to meet a water quality standard weighted equally with a ton of manure nitrogen in the form of ammonia managed to reduce air emissions. This does not imply that zero emissions will occur to either air (see Figure 3) or water (see Figure 2). Nor does it confer any value to reductions in potential impairment of air or water resources. Moreover, potential interactions across air and water emissions are not considered here. It does imply that manure nitrogen is being managed according to the technology standards described in the policy analysis.

The quantities of manure N that can be managed when only water standards are in place, Policy A, range from 26,000 tons when considering only CAFOs to over 73,000 tons when all AFOs are required to meet agronomic application levels. This level of control is achieved at regional cost of from $30 to over $145 million. (See the report by Ribaudo et al., 2003, for a more complete description of this alternative.)

When water standards for agronomic application are combined with simultaneous efforts to reduce the air emissions, significantly more manure nitrogen is managed, at a potentially substantial higher cost. Including air emission controls with water quality standards for CAFOs brings the quantity of nitrogen managed to about 66,000 tons at a cost of $47 million. Expanding the number of farms increases both the cost and quantity of manure nitrogen managed. About 220,000 tons of manure nitrogen is managed if all AFOs are included in the simultaneous management of air and water emissions, but at a cost approaching $186 million. Both the quantities of nitrogen managed and the cost would be higher, but the model exhausts all available land in the allowed transportation distance before finding adequate land for manure application at the 30% willingness to accept level (Higher willingness to accept levels do result in adequate land for disposal. For example, a willingness to accept manure of 70% at the all AFO level manages about 10% more manure nitrogen at the same cost as shown in Figure 4.)

While current Federal regulations address land application of manure produced on CAFO operations, there are as yet no regulations on air emissions. Accordingly, we examine the case where emission controls for alternative farm sets are added to current Federal water quality standards for manure produced on CAFOs. We estimate the joint air and water costs of land applying manure at $47 million to manage 66,000 tons of manure nitrogen (same as in Policy B.) However, adding the cost of the air emission controls (alum, lagoon covers, and increased incorporation) without simultaneous land application controls places this policy on a different resource management trajectory, with the all AFO case costing $71 million to manage about 110,000 tons of manure nitrogen.

Several conclusions about the effectiveness and cost of policies examined are exhibited in Figure 4. First, water quality policies alone will only achieve about 75,000 tons of manure nitrogen management at any cost. Air control policies will need to be included as a part of the policy set if a level greater than 75,000 tons needs to be managed to achieve environmental goals. Second, it is cheaper and more effective to manage nitrogen for both air and water quality on CAFO manure only than to manage manure nitrogen from CAFOs plus 25% of the remaining AFOs at a given management level. Third, levels of nitrogen management greater than 110,000 tons can be achieved only through simultaneous management of manure air emissions with agronomic land application rates.

4. Average Costs

The average cost of increasing the quantity of manure nitrogen managed is presented in Figure 5. Values reflect changes relative to the current Federal requirement of land-applying manure from CAFOs in an agronomic manner. The average cost per ton under Federal requirements for CAFOs is estimated at $1,100 per ton of N managed, based on a willingness to accept manure on 30% of acreage. The per-ton cost rises to almost $2,000 per ton if all AFOs were subject to Policy A. One alternative to reduce the per-ton cost is to increase landowner willingness to accept manure. The cost per ton decreases by 6 to 12 percent at a willingness to accept level of 70%.

Costs per ton to increase the quantity of manure nitrogen managed are lower for policies that include managing air emissions, with costs increasing at a decreasing rate. For Policy B—managing water and air simultaneously—the per-ton costs ranged from $722 to $833 per ton, with possible savings of 10 percent possible at a 70% willingness to accept level.

The computation of an average cost per ton leads to an initially declining per-unit cost with Policy C. While the total costs increase, spreading the initial high costs of agronomic land application of CAFO manure over increasing quantities of manure-nitrogen managed on additional AFOs results in lower average costs.

5. Subregional Evaluation

Reported results have emphasized costs and nitrogen management outcomes at a regional scale. However, aggregate measures of regional costs for a given policy can mask significant variation at a subwatershed scale. Regional variation reflects spatial variation in animal concentrations relative to land availability, as well as differences in animal species makeup, manure storage and handling systems, cropping patterns, and other factors. Regulations may have varying effects on the animal sector, with implications for optimal policy design.

Six multi-county subregions were defined, based on county-level ratios of excess manure production (manure N that exceeds crop requirements on the source farms) to land available locally for manure spreading (Figure6). Three subregions (SR1 – SR3) represent areas where production of confined animals is heavily concentrated and land for manure spreading is relatively limited. In these areas, an average of less than two acres of cropland

and pastureland were available per ton of excess manure. Three additional subregions (SR4 – SR6) represent areas with lesser concentrations of manure production relative to spreadable area. In these areas, there were more than 25 acres available per ton of excess manure.

Average manure hauling distances are evaluated under four hypothetical conditions for Policy A (Table 1). The table reflects alternative assumptions on both the share of confined animal operations required to meet a nutrient standard for land-applied manure and landowner willingness to accept manure on their fields. Where animal production is concentrated, manure-handling costs faced by producers are determined largely by the spatial distribution of land area available for manure application and the level of competition among animal farms for available land; those two factors together determine the hauling distance required to access available land. Hauling distance is an important component of total costs, accounting for over 60 percent of total regional costs. Hauling distance changes at the subregional level provide a direct proxy for subregional costs that are not currently available.

Average manure hauling distances for land-applied manure were computed for each of the CBW subregions. Average hauling distances are generally low for confined animal operations in subregions 4, 5, and 6, characterized by lower concentrations of confined animal production. In these areas, the majority of manure produced is used on the source farm and limited excess manure is transported relatively short distances as competition for available land for manure spreading is generally low. With only CAFOs meeting an N standard for applied manure and an assumed WTAM of 30 percent of acres, average hauling distances were less than 2 miles in each of the three subregions. Average hauling distance were generally shorter in subregions with higher spreadable land area per ton of manure excess, with the shortest hauling distance in south-central NY.

In contrast, average hauling distances are considerably higher for subregions 1, 2, and 3, where excess manure nutrients often exceed the assimilitative capacity of the local landbase. Competition for available spreadable land under base-case assumptions resulted in average hauling distances ranging from 3.1 to 54.6 miles. As with subregions 1-3, average hauling distance varied inversely with spreadable land area per ton of manure excess. The greatest hauling distances occurred in subregion 1 (northwest VA / eastern WV), reflecting very low land to manure ratios and comparatively low nutrient uptake rates (i.e., lower rates of applied manure under a nutrient standard) on area farmland.

Policy adjustments to the base case may have a differential impact on producer costs, depending on spatial relationships involving manure and land. An increase in landowner incentives to accept manure—expanding the supply of spreadable land to 70 percent of farm acres—would reduce hauling distances in virtually all areas. However, the impact is much more significant in subregion 1 where competition for land is greatest, with average distance declining from 54.6 to 6.3 miles. Subregional spatial considerations may be important in effective targeting of incentives to enhance landowner acceptance of land-applied manure on cropland.

Similarly, policy adjustments that require all AFOs to meet land application standards may affect the animal sector differently across subregions. Such a broadening of policy would have little measurable effect on average hauling distances for subregions 2, 4, 5 and 6, where competition for land is limited. However, broader policy coverage resulted in substantially higher costs in subregions 1 and 3 due to higher concentrations of confined animal production. The greatest change occurred in subregion 1 (northwest VA / eastern WV), where an increase in the number of farms meeting land application standards would substantially expand hauling distances under both the 30 percent and 70 percent assumptions for manure acceptance. In general, where competition for land is strong, an increase in landowner acceptance of manure can help to offset the effect of an expansion in farms required to meet land application standards.

Adding air emission controls to land application standards for water quality—moving from Policy A to Policy B—increases the subregional manure hauling distance substantially. Greater hauling distances reflect expanded acreage requirements to apply manure of higher nutrient content. However, the effect of air emission controls varies widely across subregions, as shown in Table 2, where water standards and air controls are applied simultaneously. Comparing Policies A (Table 1) and Policy B (Table 2), average hauling distance generally increased. (Distances remained constant in subregion 4.) Hauling distances increased most significantly in subregions 2 (southeast PA) and 3 (southeast MD/southern DE), areas in which production of confined animals is concentrated. In subregions 4, 5, and 6, the effect of air emission controls had a fairly significant effect on hauling distances, in terms of percentage change from Policy A to B. However, hauling requirements remained low relative to subregions 1, 2, and 3 due to differences in the land and animal densities. In general, increases in hauling distance were most pronounced under a willingness to accept manure of 30 percent, reflecting the constrained supply of cropland for manure spreading.

Summary

Animal producers in the Chesapeake Bay watershed face significant costs to meet regulations and guidelines for water quality protection. New air emission controls, if implemented, would most certainly increase costs to the sector. Cost increases reflect both the cost of the emission reduction practices and the increased costs of meeting land application standards. The need to spread manure applications over expanded acreage to comply with nutrient application standards is complicated by the implementation of air emission practices that retain more of the nitrogen in the manure. Air emission controls reduce the per-acre application rate and increase the acres needed to apply the manure from a fixed stock of animals. In areas where land available for spreading manure is limiting, manure quantities may exceed the assimilative capacity of the existing land base, raising policy concerns regarding the feasibility of relying solely on land application as a regional manure management solution. This is particularly true if the number of animal operations expected to meet both water quality and air emission guidelines is expanded.

The modeling of animal waste management highlights the key challenge in meeting both nutrient standards to limit the potential for water pollution and targeted reductions in ammonia emissions from confined animal production. Cost estimates for managing manure from animal agriculture in the Chesapeake Bay watershed ranged from $30 million to more than $190 million. The range depends on the structure and emphasis of the policy—water-quality and/or air-quality control and the number of farms targeted, which provides alternative levels of nitrogen managed. If excess manure nitrogen that potentially impacts water resources is added to the ammonia nitrogen emissions that potentially impact air resources quality, the quantity of manure nitrogen under management control ranged from 26,000 to 220,000 tons depending on policy structure and scope.

Comparing the cost per ton of manure nitrogen managed for water and air quality, the costs are lower in policies that include air controls. However, requiring non-CAFOs to reduce air emissions, without accompanying land application restrictions, would likely result in a greater over-application of manure-nitrogen on those farms, with implications for water quality in the Chesapeake Bay. At the same time, water-quality standards in the absence of air emission controls provides little air quality benefit, and may increase air emissions in some cases. Joint policy that considers water and air impacts simultaneously are needed to achieve the greatest overall reductions in manure nitrogen loss to the environment. If policies were put in place to manage all the manure nutrients in the region, other policy measures, such as increasing landowner willingness to accept manure, developing industrial uses for manure, subsidizing the long-range transport of manure out of the watershed, or even reducing herd size, may be required.

Findings from our application on the costs of manure management suggest that the spatial relationships in land and production are important. Land for manure spreading is limiting in areas where animal production is most concentrated. Competition for spreadable land results in increased hauling distances, with the most significant cost effects observed in sub-watershed areas where the ratio of animal production to farmland is greatest. Indeed, it would be difficult to accurately assess manure hauling costs in many animal-producing areas of the country without considering the spatial relationship of animal operations and available landbase off the farm.

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Table 1. Effect of Competition for Spreadable Land on Average Manure Hauling Distance by Subregion, Policy A, Water Standards only, Chesapeake Bay Watershed

Selected sub-watershed areas with lower and higher concentrations of excess manure nutrients	Available land area per ton of excess manure (N standard)	Large farms (CAFOs) only meeting N standard for applied manure		All Animal Farms (All AFOs) meeting N standard for applied manure	
		30 % WTAM	70 % WTAM	30 % WTAM	70 % WTAM
	Acres per ton	miles	miles	miles	miles
Lower manure-nutrient concentrations					
SUB-REGION 4 (south-central NY)	**61.0**	**0.4**	**0.4**	**0.5**	**0.4**
SUB-REGION 5 (north-central PA)	**28.4**	**1.6**	**0.8**	**0.4**	**0.3**
SUB-REGION 6 (central VA)	**40.1**	**1.2**	**0.5**	**1.8**	**0.9**
Higher manure-nutrient concentrations					
SUB-REGION 1 (northwest VA / eastern WV)	**.5**	**54.6**	**6.3**	**77.2**	**44.5**
SUB-REGION 2 (southeast PA)	**1.7**	**2.8**	**1.7**	**2.7**	**1.5**
SUB-REGION 3 (southeast MD / southern DE)	**1.1**	**3.1**	**1.8**	**10.6**	**3.3**

Table based on meeting a nitrogen standard for CAFOs and all AFOs, with landowner willingness to accept manure (WTAM) of 30% and 70%

AU = animal units, defined as 1,000 pounds of live animal weight (Gollehon, et al., 2001)

WTAM = landowner willingness to accept manure (Ribaudo, et al., 2003)

Table 2. Effect of Competition for Spreadable Land on Average Manure Hauling Distance by Subregion, Policy B, Simultaneous Water and Air Standards, Chesapeake Bay Watershed

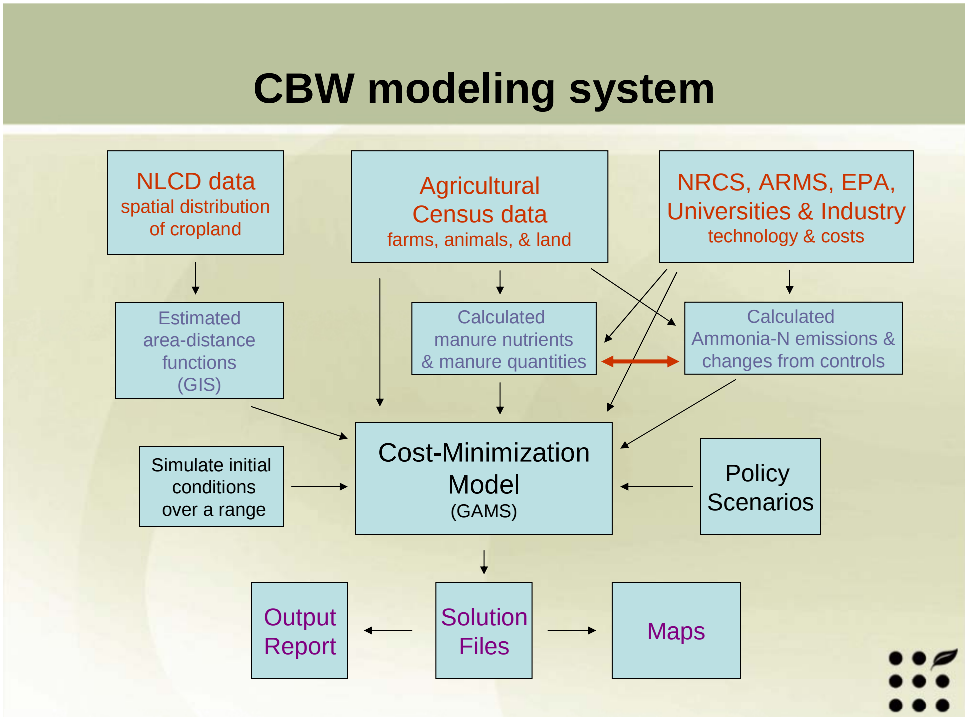
Selected sub-watershed areas with lower and higher concentrations of excess manure nutrients	Available land area per ton of excess manure (N standard)	Large farms (CAFOs) only meeting N standard for applied manure		All Animal Farms (All AFOs) meeting N standard for applied manure	
		30 % WTAM	70 % WTAM	30 % WTAM	70 % WTAM
	Acres per ton	miles	Miles	miles	miles
Lower manure-nutrient concentrations					
SUB-REGION 4 (south-central NY)	16.0	0.4	0.4	6.5	4.0
SUB-REGION 5 (north-central PA)	5.7	2.6	1.3	3.4	1.6
SUB-REGION 6 (central VA)	39.1	4.7	2.7	6.8	3.1
Higher manure-nutrient concentrations					
SUB-REGION 1 (northwest VA / eastern WV)	.5	64.1	29.9	85.4	58.4
SUB-REGION 2 (southeast PA)	1.1	8.5	3.7	43.2	6.0
SUB-REGION 3 (southeast MD / southern DE)	1.0	4.2	2.4	109.2	5.4

Table based on meeting a nitrogen standard for CAFOs and all AFOs, with landowner willingness to accept manure (WTAM) of 30% and 70%

AU = animal units, defined as 1,000 pounds of live animal weight (Gollehon, et al., 2001)

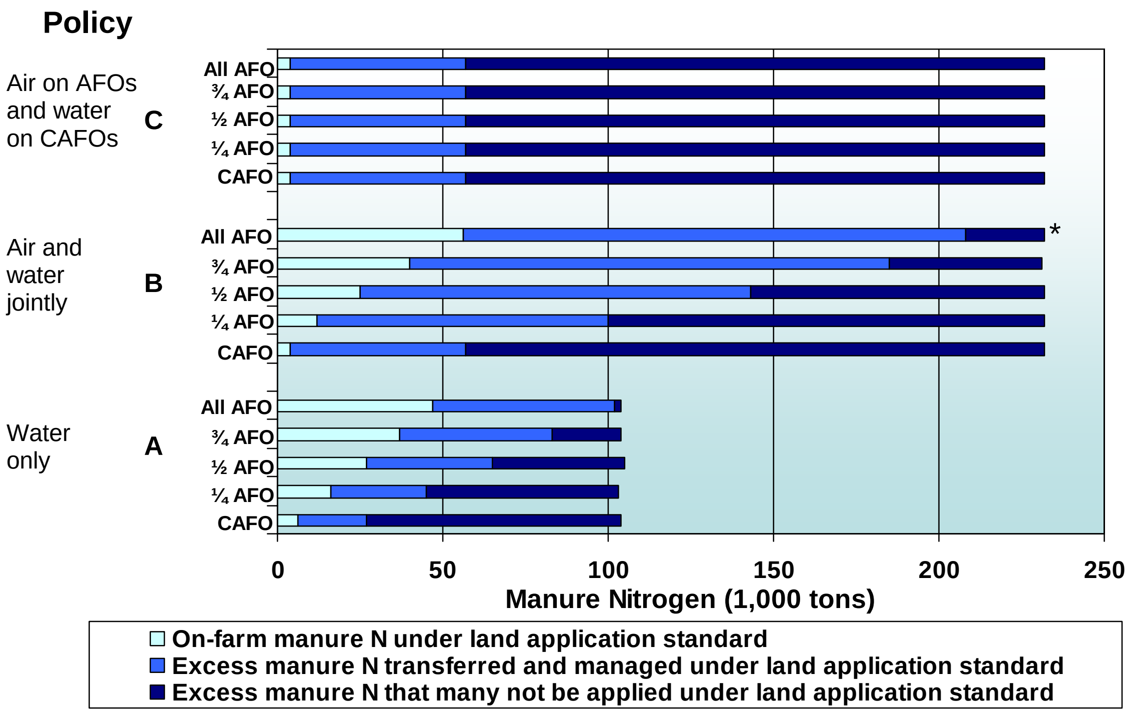
WTAM = landowner willingness to accept manure (Ribaudo, et al., 2003)

Figure 1. Modeling System Overview



Source: USDA-ERS

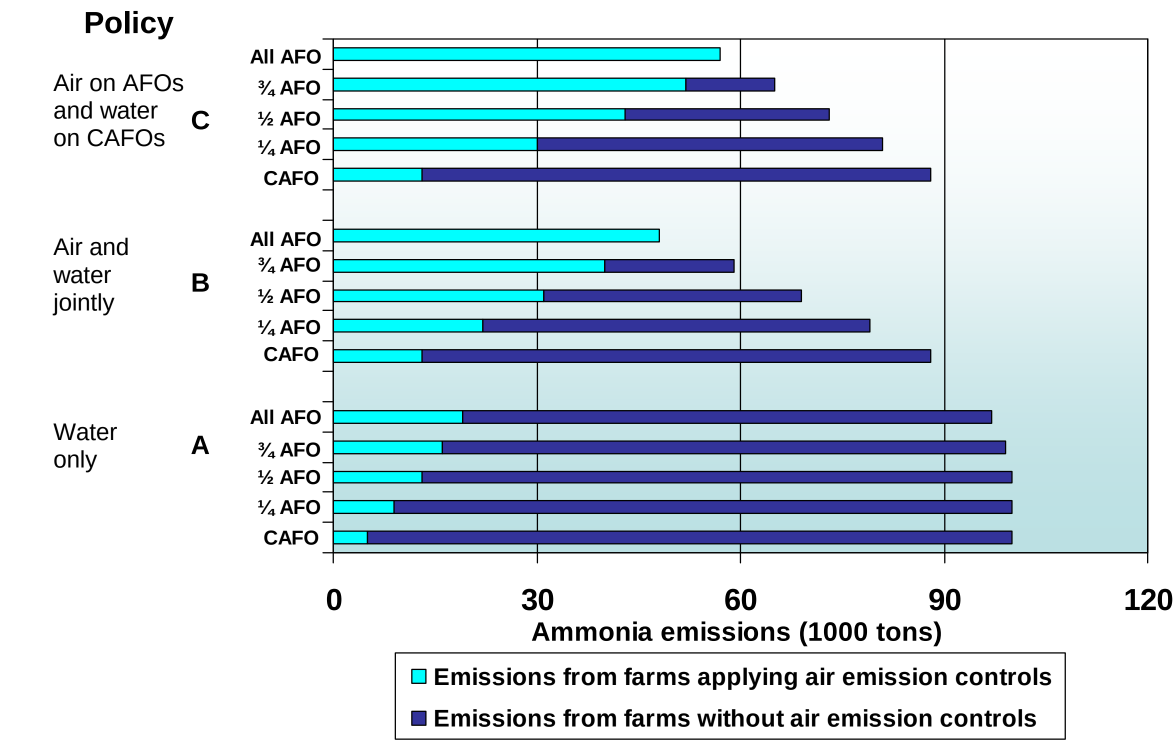
Figure 2. Manure nitrogen managed for water quality improvement, by policy alternative and farm numbers, Chesapeake Bay Watershed



*Regional manure application capacity is exceeded in this alternative.

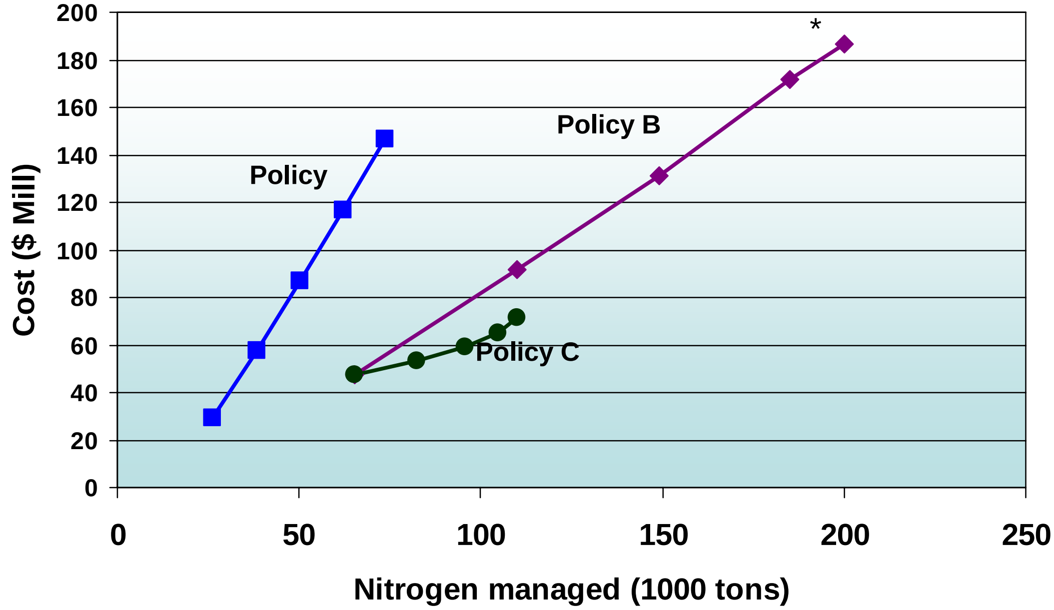
Source: USDA-ERS

Figure 3. Ammonia emissions from farms and fields, by policy alternative and farm numbers, Chesapeake Bay Watershed



Source: USDA-ERS

Figure 4. Regional Cost of Manure N managed under standard, by policy alternative and farm numbers, Chesapeake Bay Watershed

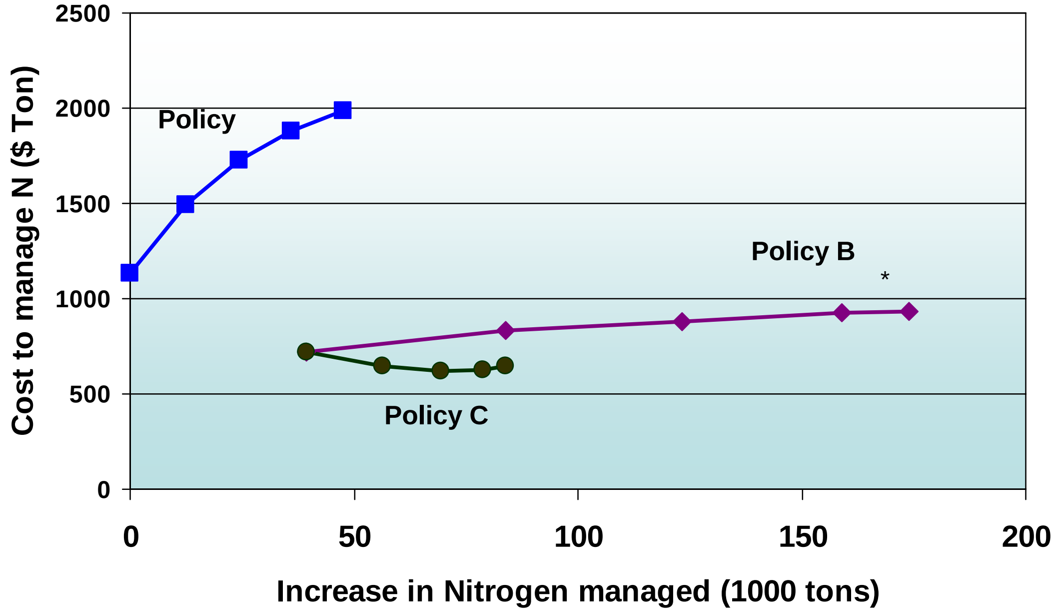


Nitrogen managed includes the N in the excess manure transferred and ammonia air emissions controlled.

*Regional manure application capacity is exceeded in this alternative.

Source: USDA-ERS

Figure 5. Regional Average Cost of increased manure N managed, by policy alternative, and number of farms, Chesapeake Bay Watershed

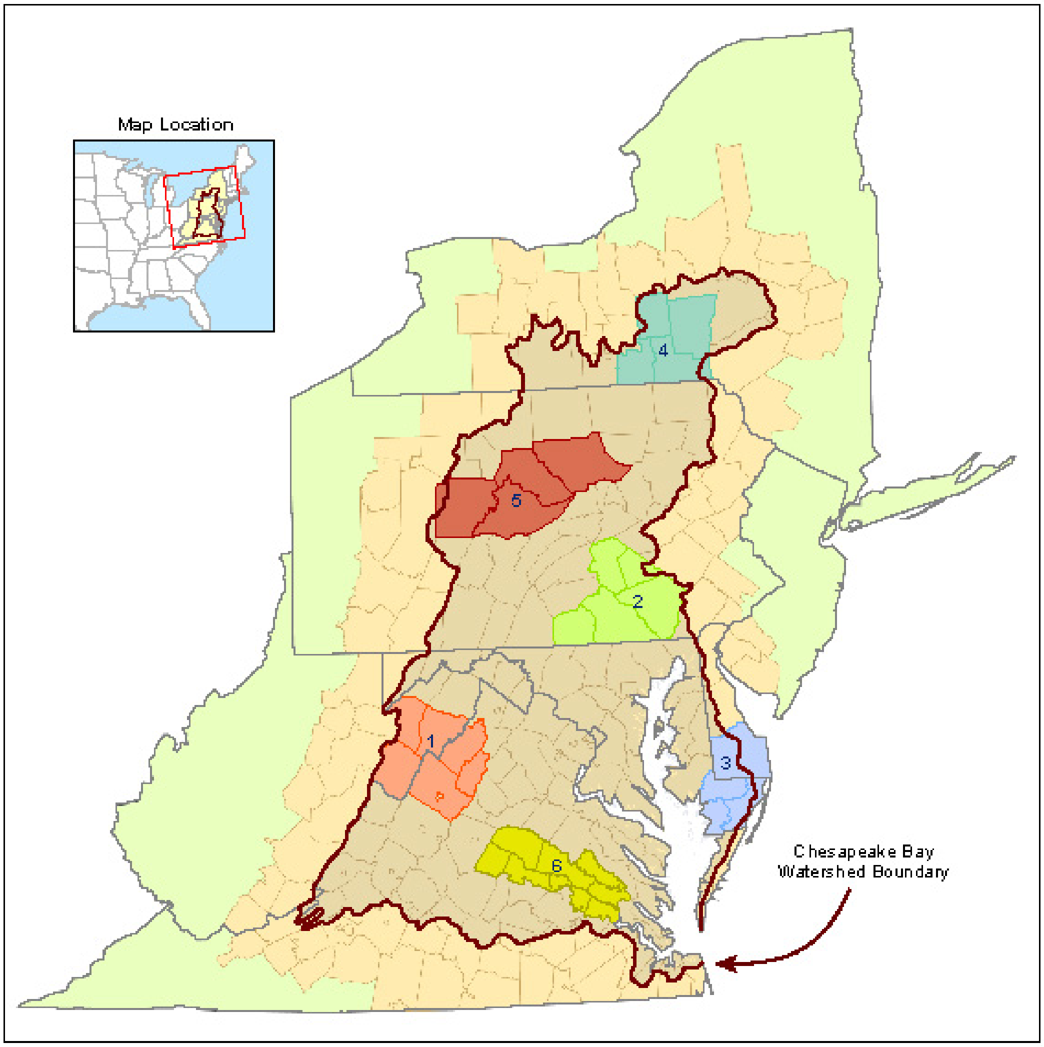


Nitrogen managed includes the N in the excess manure transferred and ammonia air emissions controlled.

*Regional manure application capacity is exceeded in this alternative.

Source: USDA-ERS

Figure 6. Model Sub-regions, Chesapeake Bay Watershed



Source: USDA-ERS