

Chapter 4—Regional Analysis: Costs and Distribution of Manure Management

The costs associated with meeting USDA goals and EPA regulations for improved manure management depend not only on individual farm conditions—addressed in our farm-level analysis (chapter 3)—but on the *interaction* among animal operations, within the broader context of off-farm resource conditions. The farm-level analysis implicitly assumes that there are no other sources of manure in the area surrounding the surveyed farms that might also need land for spreading. This chapter addresses manure management from a regional perspective, focusing on the challenges all animal feeding operations (AFOs) may face in finding suitable land for manure application when there are many producers in the same region needing to apply manure off the farm.

The geographic distribution of animal manure and land available for manure application varies significantly across the Nation. Kellogg et al. (2000) and Gollehon et al. (2001) identified areas where confined animals produce more manure nutrients than can be assimilated on cropland and pastureland in the county of production, when applied at agronomic rates. Notable among these areas were several county clusters within the Chesapeake Bay watershed (fig. 4-1).

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 loads to waters in the region have resulted in eutrophication and related ecological shifts that harm wildlife and aquatic resources (Preston and Brakebill, 1999).

The Chesapeake Bay watershed (CBW) spans over 160 counties in 6 States, and includes 66,600 farms with an estimated 8.5 million acres of land available to receive manure. The CBW included approximately 15,900 farms with 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 and 44,000 tons of recoverable manure phosphorus annually. Even if confined animal operations fully utilized the crop and pasture land under their control for manure application (and data from the farm-level analysis suggest they do not) only

about 40 percent of the manure nitrogen and 30 percent of the manure phosphorus produced could be assimilated onfarm. Clearly, applying manure at agronomic rates would require moving significant quantities of manure off animal production farms.

In areas of the Chesapeake Bay watershed where confined animal production is concentrated, implementation of EPA and USDA manure policies poses tremendous challenges. If the manure produced exceeds potential local use, producers may choose to: (1) transport the manure ever-greater distances until enough land can be found for application, (2) alter feed management to reduce nutrient output, or (3) apply technologies that transform the manure to a value-added product that is more readily transportable and usable. Beyond this, the only recourse is to reduce the number of animals in the watershed. Florida recently reduced its numbers via a Dairy Buyout Program to slow nutrient runoff from dairy farms in the Lake Okeechobee watershed (Schmitz et al., 1995).

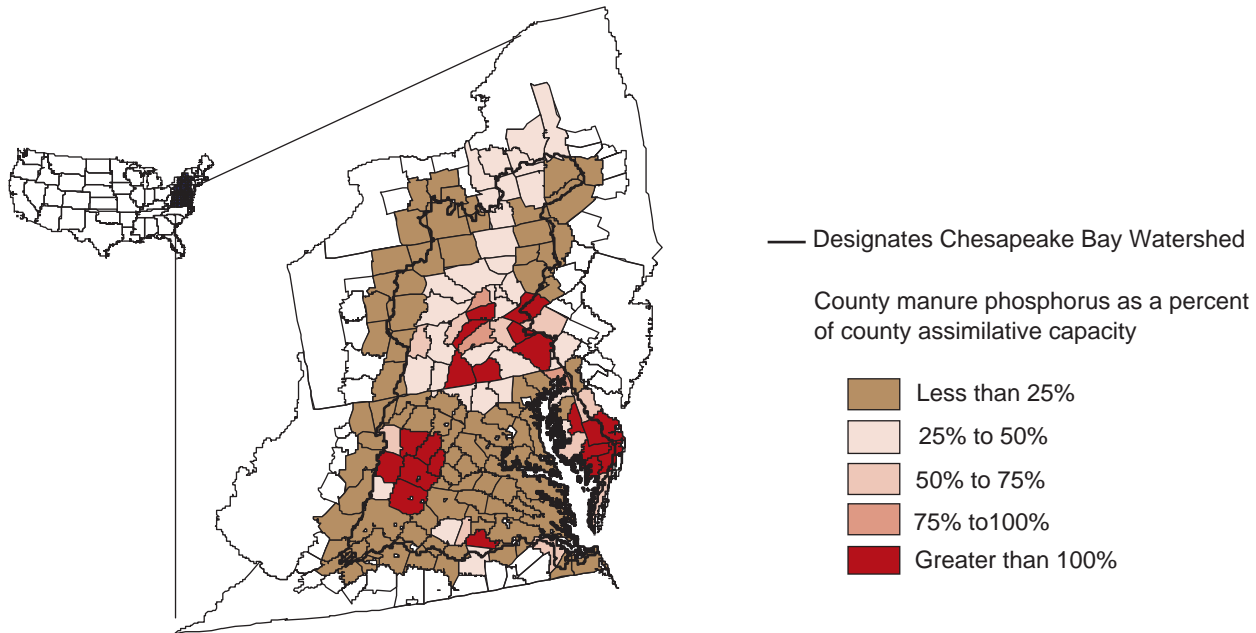
In this chapter, we present an analysis based on a regional model of manure management that accounts for the competition for spreadable land among animal producers in the Chesapeake Bay watershed (CBW). We assume that all AFOs are trying to meet the nutrient management goals laid out in the USDA-EPA Unified Strategy. The model and its results reflect a regional planning perspective emphasizing the cost determinants and feasibility of alternative strategies at the watershed scale.

Modeling Manure Management in the Chesapeake Bay Watershed

We first evaluate the feasibility of a land application strategy, allowing for out-of-county transport and considering alternative levels of willingness of landowners to use manure. Our model is designed to minimize the total regional costs of manure management, transport, and application for use on agricultural lands in the CBW, given the existing structure and scale of the animal industry and existing manure storage technology. The regional specification captures the element of competition by modeling access to spreadable land, ensuring adequate area for land application of all

Figure 4-1

The Chesapeake Bay Watershed with manure phosphorus relative to county assimilative capacity for modeled counties, with counties outside the watershed used for manure application



Source: Gollehon, et al., 2001

manure produced in the region, and computing the associated hauling costs. Explicit modeling of competition for land on which to spread manure differentiates the model from existing farm-level models.

The model was developed to: (1) provide a mechanism to track manure and related nutrient flows within the basin, from AFOs to site application and use; (2) compute the regional costs of applying manure to land, given the manure movement dictated by the nutrient flow; and (3) provide a framework for evaluating proposed land application regulations and alternative nutrient management policies (see box, “Nutrient Standards”).

The county is the primary modeling unit. The county-level specification provides consistency with Census of Agriculture data and other data, and permits 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. Details of the model are in Appendix 4-A, “Modeling Manure Management in the Chesapeake Bay Watershed.”

Applying Manure to Land in the Chesapeake Bay Watershed

Feasibility of Land Application

Land application of manure under a nitrogen (N)-standard would require about 2.5 million acres of crop and pasture land in the CBW and surrounding counties, or almost 40 percent of the 6.6-million-acre agricultural (crop and pasture) land base. A phosphorus (P)-standard would require about 4.8 million acres of crop and pasture land, or almost three-fourths of the agricultural land base.

Confined animal farms in the CBW having to meet either an N or a P standard would run out of land on which to spread manure within the modeled transportation radius if WTAM falls below certain thresholds (bar chart portion of figure 4-2).⁷ The willing-

⁷ The structure of the model necessitated identifying the allowable transport options by specifying the counties available for receiving manure from each county that could possibly export manure. Counties within a 60-km radius of the county boundary were identified in most areas. In areas with high manure production, a 150-km radius was used. The actual transport distance is generally greater since the distance within both the source and destination county is considered and adjustments are made to convert radius distance to road distance.

Nutrient Standards

USDA's Natural Resources Conservation Service (NRCS) has devised policy and developed a conservation practice standard for nutrient management that address the requirements for land application of manure nutrients (USDA, NRCS, 1999a). Land application is the preferred method of utilizing manure because these materials can supply large amounts of nutrients for crop growth, thereby reducing the need to apply commercial fertilizers. Nutrient management criteria are established by the NRCS conservation practice standard to provide adequate nutrients for crop growth and to minimize the potential for adverse environmental effects.

NRCS' nutrient management policy and conservation practice standard criteria are implemented by animal feeding operations through the development and implementation of site-specific nutrient management plans, as defined in the NRCS General Manual, Title 190, Part 402 (1999c); and the NRCS Conservation Practice Standard, Nutrient Management (Code 590) (1999a). The primary criteria within these policy documents are that land application rates of nutrients be based upon Land Grant University nutrient application recommendations. NRCS policy permits manure application rates that are determined using either a nitrogen or phosphorus standard. Manure application rates that are based on a nitrogen standard would supply all the nitrogen recommended for the crop. Manure applied at a nitrogen standard will usually result in overapplication of phosphorus. NRCS policy permits use of the nitrogen standard on sites for which there is a recommendation to apply phosphorus, or when the use of a risk assessment tool has determined that the site has acceptable risk for offsite transport of phosphorus. (The Phosphorus Index is currently the most widely used risk assessment tool for this purpose.)

Manure application rates that are based on a phosphorus standard supply only the amount of phosphorus that is recommended, based on current soil tests or a function of the phosphorus content of plant biomass removed at harvest. Manure applied based on the phosphorus standard will not usually supply the recommended amount of nitrogen, necessitating the application of additional nitrogen from other sources. When using the phosphorus standard, NRCS policy permits an application of phosphorus equal to the amount of phosphorus contained in the biomass of multiple years of crops grown on the site, provided that the nitrogen recommendation rate for the first year is not exceeded. This allows farms that have enough land to continue to apply manure on the basis of a nitrogen standard, but rotate manure applications to other sites so that a single site receives manure infrequently. Consequently, operations with sufficient land can meet nutrient management criteria without actually applying manure at rates based on a phosphorus standard. This generally is advantageous to the producer because it can be difficult to achieve a phosphorus rate of application with existing manure application equipment. Operations without sufficient land, however, will eventually need to apply manure based on a phosphorus standard on all available onfarm acres as the phosphorus levels in the soil build up. Alternatively, producers may export the manure off-farm for land application or alternative use. For the model results in this report, nutrient management criteria were represented by two scenarios: application at N-standard rates for all farms and application at P-standard rates for all farms. Neither is intended to reflect expected implementation strategies, because in practice there will be some farms that can meet criteria with N-standard rates and others that will need to adopt the more restrictive P-standard rates. In a related study on the costs of implementing comprehensive nutrient management plans, NRCS estimated that about 30 percent of livestock operations would need to use P-standard rates to meet nutrient management criteria; the remaining 70 percent have sufficient land available to apply manure based on a nitrogen standard. We did not have the data on soil characteristics and historical land use to determine in our analyses the share of land that would need to meet a P-standard. The two scenarios used in the present study are intended to establish upper and lower bounds on the costs associated with implementing nutrient management plans.

ness-to-accept-manure (WTAM) threshold at which available land reaches its capacity for assimilating manure nutrients is estimated at 60 percent for a P-standard and 20 percent for an N-standard. Current use of manure on field crops is in the 10- to 20-percent range nationally. Several options exist for disposal of surplus manure that cannot be absorbed on available land:

- Increasing landowner willingness to accept manure through technical and financial assistance can expand the spreadable area while reducing hauling distances.
- Greater reliance on off-farm processing to create manure-based products both reduces the quantity of manure requiring agricultural land application and

expands the spreadable area to nonagricultural lands, such as golf courses and lawns.

- Farms in the region can increase manure-nutrient uptake through both cropping pattern adjustments and yield enhancements from improved management and technologies, such as irrigation.
- Animal producers can reduce the nutrient content of manure through improved rations and the use of additives, enabling increased manure applications per acre for a given nutrient standard (see box “Reducing Manure Nutrients Through Feed Management,” p. 19).
- Changes in animal industry structure, such as reductions in the number of animals and plant relocations, can directly reduce the quantity of manure that exceeds land application levels.

The total cost of manure disposal in the CBW represents the cost of applying manure to land (addressed in our model) *plus* costs of managing manure that cannot be land applied under assumed hauling distance limits. Our focus on land application here expands to include options like off-farm processing and feed ration adjustments. Other options—involving incentives to increase WTAM and adjust cropping patterns—will require additional programs of research.

Finally, reductions in manure via a smaller animal sector will require careful evaluation from both a producer and rural economy perspective. The national sector analysis in this report (see chapter 5) does estimate the potential loss in returns to agricultural producers from reductions in animal numbers, although these estimates do not consider impacts on the associated rural economy. Reducing animal stocks such that all manure could be land applied lowers projected net returns in the CBW by \$47 million (15 percent of total returns to the animal industry in the CBW) under an N-standard and \$164 million (51 percent) under a P-standard, assuming a 10-percent WTAM. This estimate is based on net return estimates from the national sector analysis (chapter 5). Actual costs to address the manure that cannot be land applied will depend on the combination of options utilized in the region.

Regional Costs

Regional costs considered in this analysis—consistent with the farm-level analysis in chapter 3—include selected nutrient management costs (plan development, soil testing, and manure testing), manure transport (onfarm and off-farm), and application (field spreading and incorporation). We also estimated the

savings from reduced chemical fertilizer purchases and application to compute a net regional cost of manure land application.

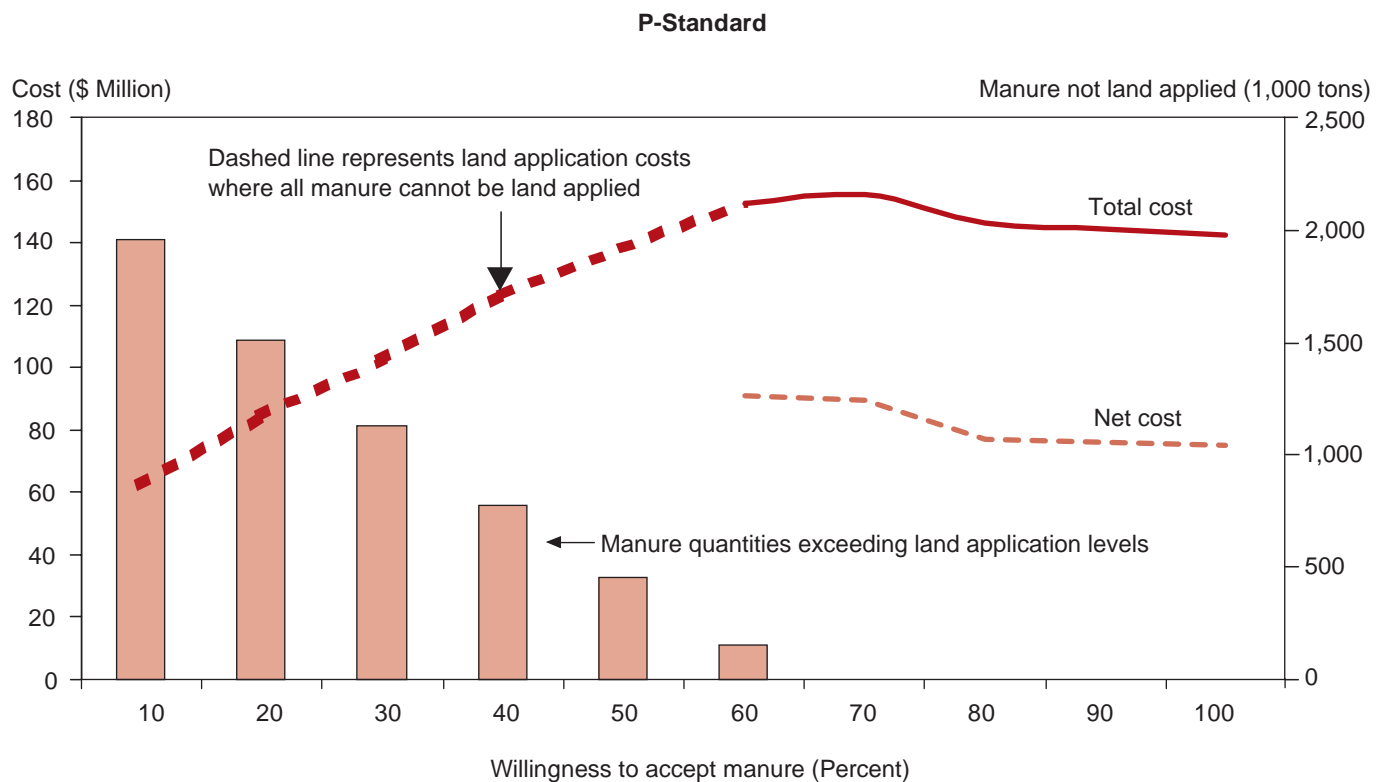
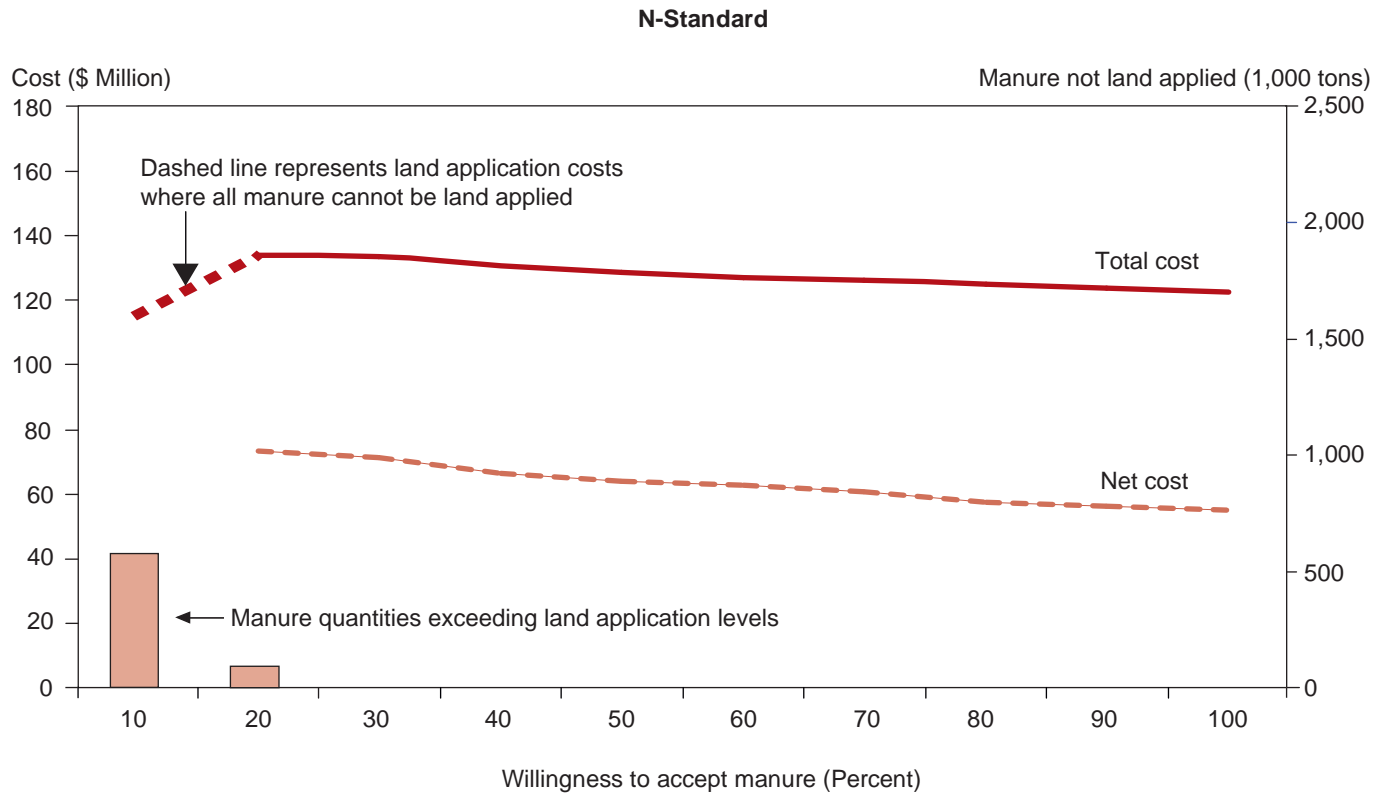
The total regional cost for management, transport, and application under an N-standard was estimated at \$134 million at a WTAM of 20 percent (current national levels for select crops are believed to be between 10 and 20 percent) (fig. 4-2). At the 20-percent WTAM level, 2 percent of manure would exceed approved land application levels. Costs decline as WTAM increases, falling to \$123 million under an N-standard with all crop and pastureland available for spreading (WTAM = 100 percent). If WTAM is less than 20 percent, the share of manure exceeding land application limits increases, and the costs for management, transport and application would decline. These estimates do not include disposal costs for manure that is in excess of what can be applied to crop and pasture land in the modeled area.

The total costs of management, transport, and application under a P-standard follow a pattern similar to the N-standard. However, costs under the P-standard would be greater and would peak at a substantially higher WTAM due to the lower per-acre application rates and increased hauling distances (fig. 4-2). At a WTAM of 20 percent, about 40 percent of manure production would be in excess of available land’s ability to assimilate phosphorus. It is not until WTAM reaches 60 percent that almost all manure produced in the watershed can be land applied. Estimated management, transport, and application costs peak at \$155 million with a WTAM of 70 percent (no excess manure). At a WTAM of 100 percent, land application costs would total \$143 million. At WTAM levels below 60 percent the quantity of manure in excess of land application increases, and the cost of manure management, transport, and application associated with crop and pasture land use declines. Clearly, at lower WTAM levels, much of the full regional cost of addressing manure nutrients will depend on the disposition of the manure that is not land applied within the CBW.

⁸ Savings in chemical fertilizer were based on nutrient costs of nitrogen and phosphorus in the region’s most common commercial form and are sensitive to assumptions on fertilizer prices, forms, and application efficiencies. Only the manure nutrients that could be utilized by crops were assigned value. In meeting a N-standard, adequate phosphorus would also be applied and the value of a reduced field operation was credited as “savings.” However, nitrogen requirements are not met under a P-standard. It was assumed that additional commercial nitrogen would be applied, so the chemical fertilizer savings when meeting a P-standard included no savings in field operations. There is currently little data on either the current level of substitution of manure for chemical fertilizer or the degree to which potential benefits of improved manure management may already be captured.

Figure 4-2

Effect of willingness-to-accept manure on manure exceeding land application levels, net and total land application costs in the Chesapeake Bay Watershed



Net land application costs are the estimated costs of management, transport, and application for land-applying manure, less the savings from reduced chemical fertilizer purchases and reduced fertilizer application costs.⁸ Chemical fertilizer savings were substantial, offsetting 45-55 percent of the total costs of land application for nitrogen and 40-47 percent of the total costs for phosphorus (fig. 4-2).

Regional Cost Components

An analysis of regional manure management must consider costs that occur off-farm, including out-of-county, which may represent a major share of the costs associated with meeting nutrient standards on AFOs. This information may help inform programs that compensate producers for specific cost components, such as transport.

Transporting manure for land application—both onfarm and off-farm—represents the largest component of total costs for manure management, transport, and application in the Chesapeake Bay watershed. Transport costs account for 64 to 67 percent of total costs (\$78-\$89 million) under an N-standard, and 63 to 67 percent (\$90-\$102 million) under a P-standard (table 4-1).⁹ Application costs were fairly constant across WTAM levels, at near \$34 million (25-27 percent) for an N-standard. For a P-standard, application costs were near \$40 million, or about 28 percent of total costs. Manure management costs (quasi-fixed costs of plan development, nutrient testing, etc.) were between 7 and 9 percent of total costs for both an N- and P-standard.

Regional costs of land application can also be reported by the location of receiving lands—onfarm, off-farm within the farm's county, or off-farm and out-of-county. Onfarm transport and application costs of manure represent the largest component of total costs in the watershed. Onfarm costs account for between 65 and 75 percent of costs, or about \$85 million, under an N-standard (fig. 4-3). Onfarm costs were fairly constant across WTAM levels, since nearly all land on farms with confined animals was used for manure application regardless of the WTAM level of crop producers.¹⁰ Confined animal farms were assumed to have a WTAM for their own manure of 100 percent.

⁹ These costs do not include the capital improvement costs that may be desirable or necessary to improve onfarm manure storage and handling systems to meet policy goals.

¹⁰ While onfarm use of manure nutrients is roughly constant across scenarios, onfarm costs decline with lower WTAM levels when all manure cannot be land applied. This is attributable to the increased onfarm use of higher nutrient and lower cost forms of manure under the regional cost-minimization framework.

Off-farm manure transfers to suitable crop and pasture land account for 25 percent of the transport and application costs at a WTAM level of 100 percent. The costs devoted to off-farm transfers would increase from \$28 million to \$43 million (25 to 35 percent) as the WTAM declines, with a shift from mainly within-county costs to primarily out-of-county costs (fig. 4-3). Few counties in the CBW need to transport manure out of county (see fig. 4-1).

A regional presentation masks many of the local cost conditions; most of the region's total out-of-county costs may occur in relatively few counties. For example, in one major exporting county, off-farm transfers accounted for 80 percent of total costs, with out-of-county hauls accounting for 76 percent of the total county cost. Within-county transport costs would decline from \$19 million to \$10 million while inter-county transport costs would increase from \$9 million to \$32 million if WTAM dropped from 100 percent to 10 percent, clearly underscoring the importance of willingness to accept manure on the transport patterns and associated costs.

The distribution of on- and off-farm transport costs for the P-standard follows a similar pattern to the N-standard, except that modeled costs peak at a WTAM level of 70 percent (fig. 4-4). Onfarm costs of transport and application were about \$80 million (60 percent of total costs) over the WTAM range of 70 to 100 percent. Intracounty costs would decline as WTAM declines. In contrast, intercounty costs increase from \$36 million to \$54 million as WTAM falls from 100 to 60 percent (fig. 4-4). Out-of-county transport costs for a P-standard are greater even at a 100-percent WTAM than for an N-standard at a 20-percent WTAM. This difference is rooted in the lower allowable per-acre application rate for P, so that fewer tons of manure can be applied on land in the county. This results in lower costs for intracounty hauling but higher intercounty costs. At the lower application rate, more acres are required in total and suitable land will be farther from the manure-producing farm.

One of the major impacts of a reduced willingness to accept manure is the need to move manure farther. The average distance that manure would be transported on manure-producing farms in the CBW is estimated at 0.35 miles.¹¹ The average distance a farm's excess manure would be transported off the farm, but within-county, ranged between 3.8 miles and 7.3 miles

¹¹ The method used to compute onfarm transportation distance likely understates the actual distance, because the algorithm assumes the farm's acres are in a conterminous, square block. Some farms manage separate land parcels spread over large areas.

Figure 4-3

Effect of willingness to accept manure on costs of applying manure to land in the Chesapeake Bay Watershed, by location of land receiving manure

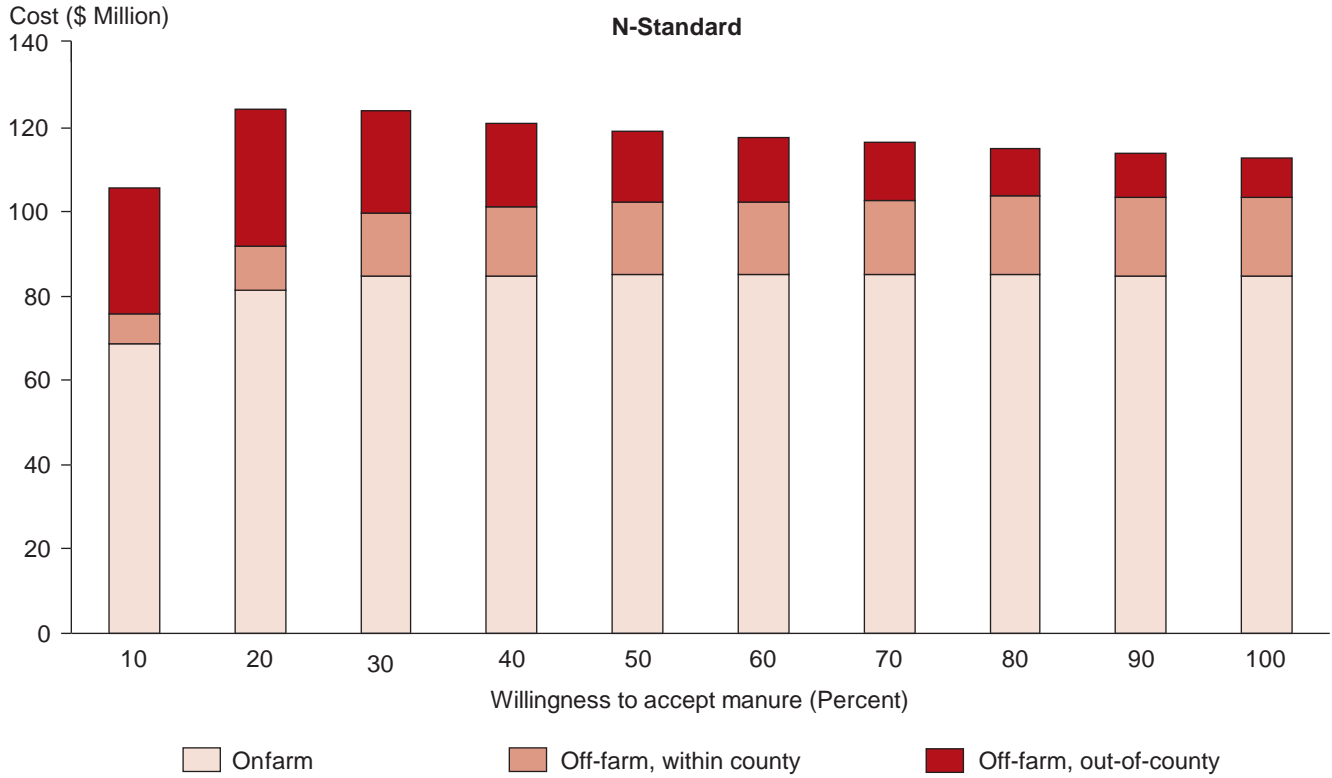
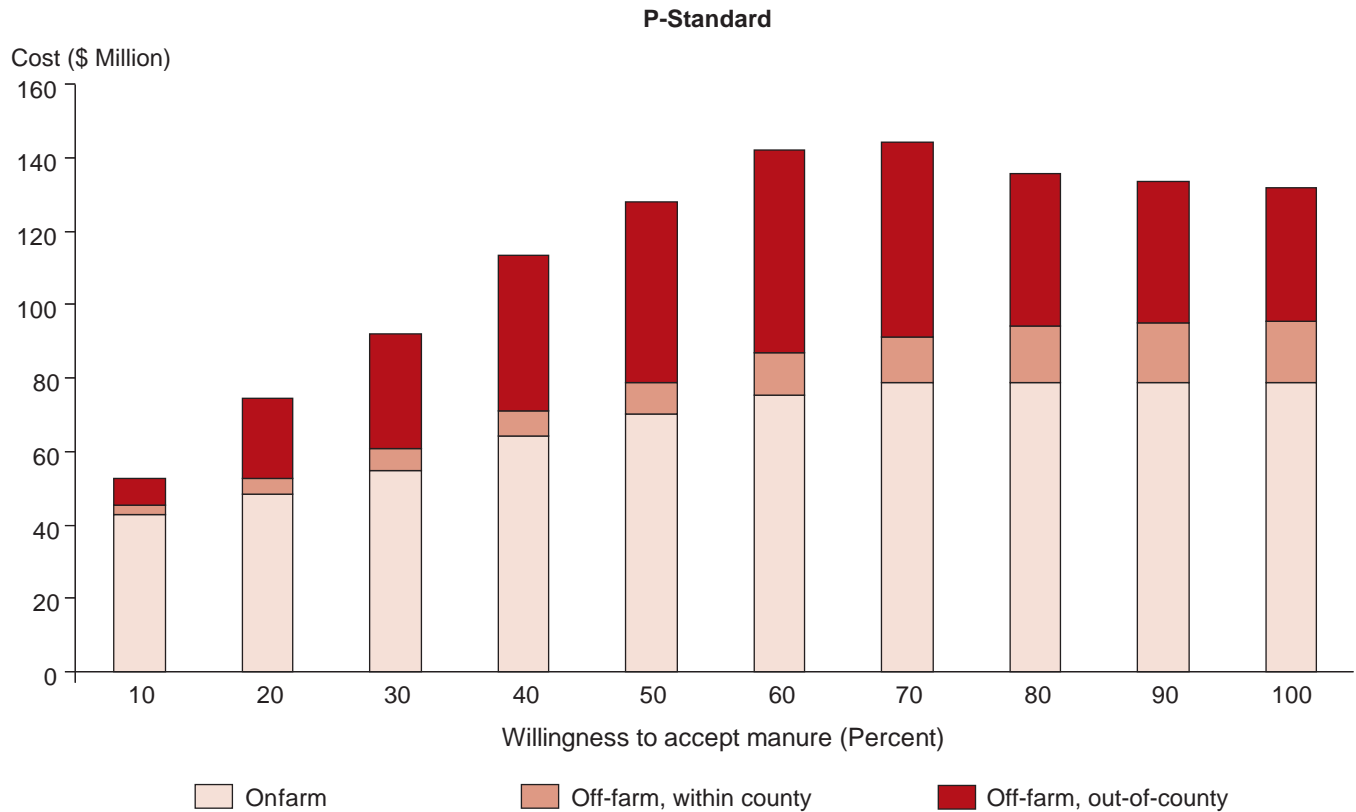


Figure 4-4

Effect of willingness to accept manure on costs of applying manure to land in the Chesapeake Bay Watershed, by location of land receiving manure



for both an N- and P-standard. Out-of-county transport distances are substantially greater, with significant differences between N- and P- standards. Under an N-standard with WTAM of 100 percent, the average intercounty hauling distance was 23 miles. Average intercounty transport distance would increase to near 75 miles at a WTAM of 20 percent. Average intercounty transport distances under a P-standard, at about 40 miles under a WTAM of 100 percent, is almost double that of the N-standard. Average intercounty transport distance would increase to near 120 miles at a 60-percent WTAM.

Our regional model is able to track the relationship between distance and the land that is potentially available for manure application. As farms utilize all of the nearby land for manure application, competition for receiving land intensifies and increases the average distance manure must be moved. The farm-level analysis (chapter 3) estimated that the average distance a large hog farm in the Mid-Atlantic region (which includes most of the Chesapeake Bay watershed) would have to transport manure to reach enough suitable land was about 2.6 miles under an N-standard with a WTAM of 20 percent. The maximum transport distance for any one farm was 21 miles (without considering other farms in the same area also needing land for manure application). Compare this with the *average* intercounty distance of 75 miles from the regional CBW model. When the needs of all confined animal farms are considered simultaneously, the transport distance can increase considerably.

This analysis presumes a working mechanism that allows manure to move from AFOs to crop producers who can use the manure. This could be a manure broker who collects manure from farms and sells it to crop producers, or simple agreements between individual animal producers and their neighbors. Increasing the manure transport distance beyond a producer's own farm and nearby lands highlights the importance of having a manure of consistent nutrient composition that can be delivered and applied in a timely fashion. A market system that will allow the level of manure transfers needed to land apply all the manure in the CBW does not currently exist. Such a system may emerge to link manure producers with manure recipients once the new regulations are implemented and farms meet nutrient application standards.

Additional Cost of Meeting Phosphorus Standard

While the regional costs of applying manure to land were greater under the more stringent P-standard, the cost of shifting from an N- to a P-standard depends on

the WTAM level assumed. At a WTAM of 100 percent, the regional costs to meet a P-standard would be about \$20 million more than the N-standard. The additional costs to meet a P-standard would increase as the WTAM declines, with total costs about \$26 million greater than under an N-standard at a WTAM of 60 percent. At WTAM levels below 60 percent, the increased costs cannot be determined because of the growing quantity of manure that is in excess of land application capacity.

The higher costs of meeting a P-standard are mostly from the greater costs for off-farm manure transport. Off-farm transport costs under a P-standard would be \$25 million higher at 100-percent WTAM, growing to \$35 million at a 60-percent WTAM. Costs of increased movement of manure off-farm are partially offset by the reduced costs for manure utilized onfarm, since less manure could be applied onfarm. Also potentially reducing the costs of adopting a P-standard are reductions in the costs of applying manure. When soil phosphorus threshold values are acceptable, NRCS policy permits producers to apply multiple years of manure-P in a single-season application (see box, "Nutrient Standards," p. 38). Such flexibility in implementation of nutrient management policy could reduce the acres receiving manure in any given year. Curtailing manure spreading operations to meet the P-standard more flexibly could reduce costs relative to our estimates by as much as \$6 million, or 30 percent of the total cost of shifting from an N- to a P-standard, assuming all receiving acreage is eligible based on soil phosphorus thresholds.

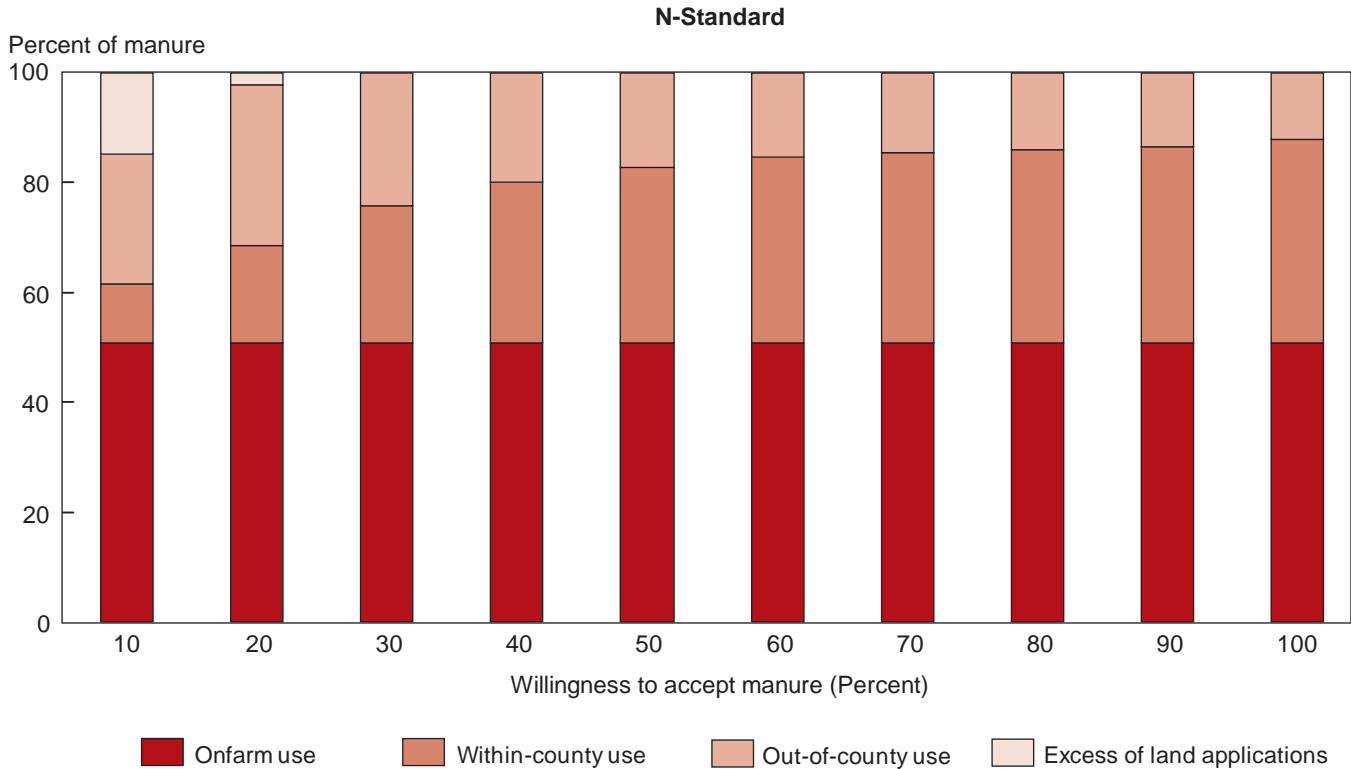
Regional Manure Disposition

Costs of meeting the nutrient standards largely reflect the transport distances associated with the quantities of manure applied onfarm, within-county, and out-of-county. Under an N-standard, just over half the manure would be applied onfarm, 37 percent in the farms' county, and the remaining 12 percent to land outside the farms' county at a 100-percent WTAM (fig. 4-5). As the WTAM declines, manure moved off the farm would be transported farther—as reflected by the increased share transported to farms outside the county—reaching 24 percent at a WTAM level of 30 percent. At a WTAM level of 20 percent, about 2 percent of manure in the watershed would be in excess of land application capacity, given the transportation limits in the model.

Meeting a P-standard would decrease the quantity of manure applied onfarm (relative to an N-standard) to less than 40 percent of total manure. The share of

Figure 4-5

Effect of the willingness to accept manure on its disposition in the Chesapeake Bay Watershed, including excess manure



manure applied in the farms’ county would also decline to 24 percent. As expected, the share of manure transported out of the farms’ county would increase substantially, with 37 percent of the manure transported to land outside the farms’ county under a 100-percent WTAM (fig. 4-6). The share of manure transported across county lines would continue to increase as the WTAM level declines, reaching 41 percent of manure produced at a 60-percent WTAM.

The growing share of intercounty manure transport as well as the increasing distance for average intercounty movement is shown spatially in figure 4-7. At a WTAM level of 100 percent, three areas of manure export prevail—the Shenandoah Valley of Virginia and West Virginia; the Delmarva Peninsula area of Delaware, Maryland, and Virginia; and areas of south-central Pennsylvania, especially Lancaster County. The composition of manure export counties remains fairly constant as WTAM levels decline, though the number of counties that are net importers of manure increase, as does their distance from the export counties.

Manure produced in the region is not uniform, but varies in quality depending on the animal type and manure system (see box, “Manure Handling Systems,” p. 47). Manure characteristics influence where manure is applied because the standards are

nutrient based and high-water manure adds weight and cost. One would expect that manure with a high water content (“wetter” manure) would be transported a shorter distance than “drier” manure, all else being equal. In the CBW, lagoon waste is the wettest form of manure, while poultry litter is the driest. Slurry is intermediate in terms of water content.

Generally, the wetter the manure, the more likely it would be used onfarm (fig. 4-8). (The model is responding to the cost per ton of material and minimizing the transport of water long distances.) Over half of the dry manure would be transported off the farm under all WTAM levels under both an N- and P-standard. Another outcome of cost-minimizing is that when available land capacity for receiving manure is reached, manure transported is that with the lowest water content.

Alternatives to Land Application

Numerous alternatives to spreading manure on land—broadly classified as “output-using” or “supply-reducing”—exist or are under development, but their applicability varies with animal species, region, and stage of development. Output-using technologies redirect the manure off-farm as an input for industrial uses. These technologies may transform the manure into a

Figure 4-6

Effect of the willingness to accept manure on its disposition in the Chesapeake Bay Watershed, including excess manure

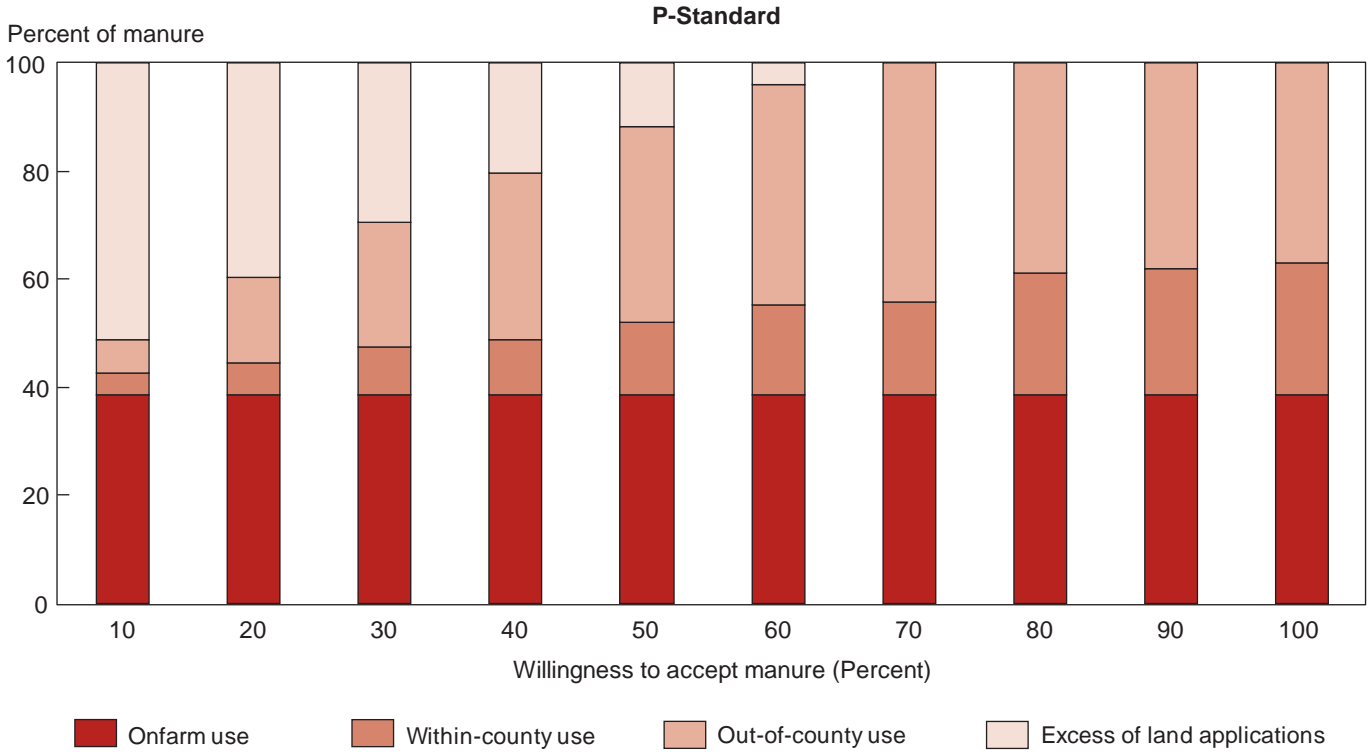
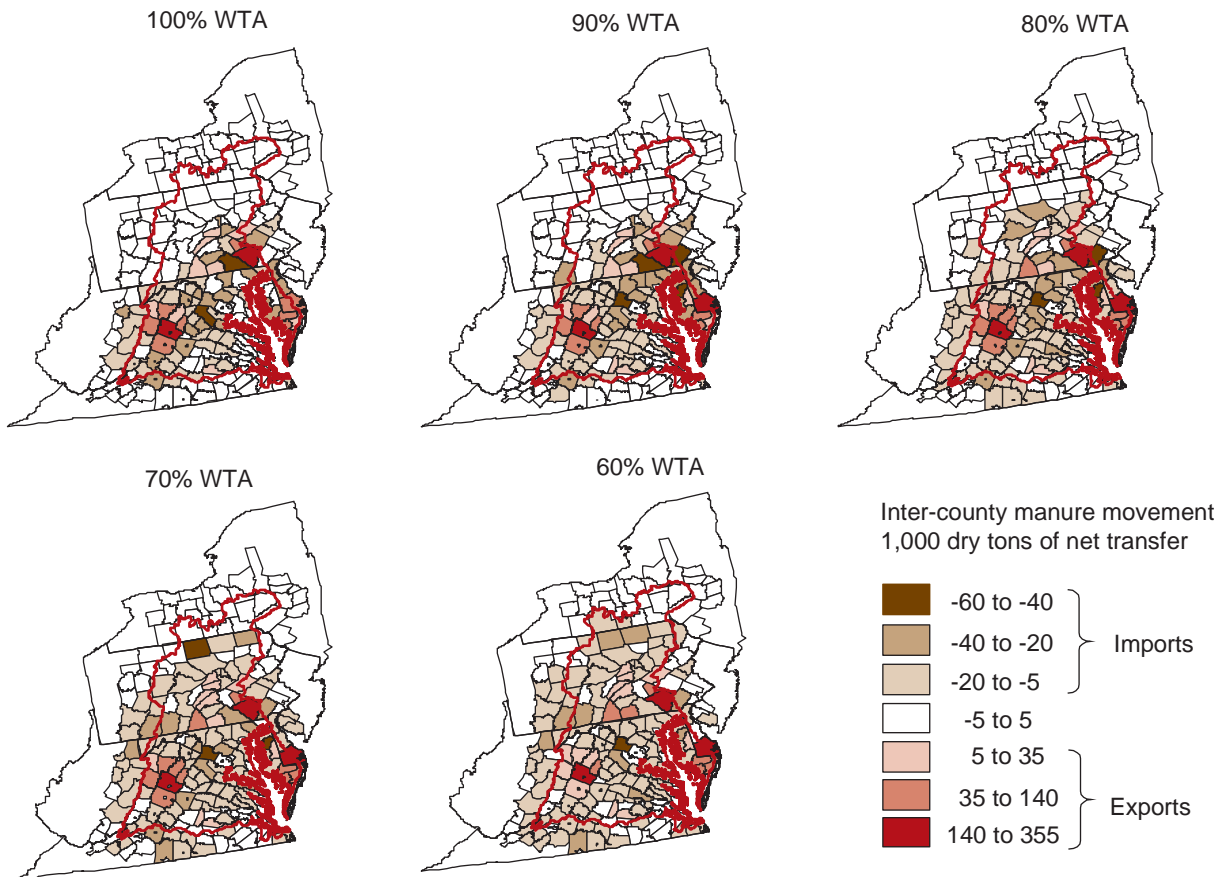


Figure 4-7

Effect of willingness to accept manure on its spatial distribution under a P-standard, 1997



Manure Handling Systems

Alternative manure handling systems play an important role in the regional model. The systems were the basis for the estimation of the wet manure transport weight and associated costs. Systems also formed the basis for the different ways manure can be transported and applied (truck, tractor and spreader, or irrigation system). Three alternative manure handling systems were included in the regional model: lagoon systems (open, uncovered storage), slurry systems (covered storage), and dry systems (primarily poultry in the CBW). All poultry in the CBW were assumed to use a dry litter system. The manure handling systems for swine and dairy in the CBW were determined from the systems reported in the ARMS for those animal types (USDA, 2002a). Feedlot beef was assigned the same system proportions as dairy. Manure handling systems were linked to an animal type and were not allowed to adjust in the current regional model.

Manure waste from lagoon systems was specified as 99 percent water; slurry systems - 95 percent water; poultry dry systems - 30 percent water, and dry systems for other livestock types - 50 percent water (USDA, NRCS, 1999b). An additional bedding adjustment, representing tons of bedding per ton of dry manure, was included for some dairy (30 percent of manure) and all poultry (10 percent of manure) production. The share of dairy systems utilizing bedding was based on ARMS data.

more homogeneous and stabilized fertilizer product, or may burn manure for power generation. Manure with relatively low moisture content, such as broiler litter, is generally better suited for use in industrial processes than “wetter” manure from lagoon and slurry systems. A supply-reducing technology reduces the amount of nutrients excreted per unit of animal output, resulting in fewer pounds of nutrients needing disposition. This can be achieved through dietary modifications.

Output-Using Technology

Industrial uses of manure in the Chesapeake Bay watershed have historically focused on composting poultry litter. The amount of poultry litter in the CBW processed by industrial facilities has increased significantly with the recent construction of two large-scale industrial facilities using poultry litter, PerdueAgriRecycle™ and Harmony Farms Shenandoah Valley (HSV).¹² These two operations transform litter into pelletized organic fertilizer, blended fertilizer products, and energy for use in fertilizer manufacturing. Other industrial processes that could divert litter from land spreading are in the planning or construction stage (see box, “Industrial Processes for Using Manure,” p. 50). For example, a large-scale, capital-intensive project to generate electricity by burning poultry litter has been proposed, but its high cost and other issues have thus far prevented its development.

PerdueAgriRecycle™, in Seaford, Delaware, is permitted to process 94,000 tons of litter annually into pelletized organic fertilizer for agricultural and landscaping uses. HSV, in the Shenandoah Valley of Virginia, is designed to process 60-65,000 tons per year of poultry litter as both an energy source and a

¹² No endorsement by USDA of the process or product is implied or inferred.

feedstock in the manufacture of a blended organic-inorganic fertilizer for the golf course and landscaping markets. Manure diverted to plants such as these would no longer be in competition for land, reducing the total regional costs of applying manure to land.

Based on proposed alternatives, we estimate that the diversion of poultry litter to industrial alternatives would be 200,000 tons per year in the near term (2002-2004) and 376,000 tons within 5 years, or 0.30 and 0.65 percent of the manure produced in the region.¹³ Near-term estimates include the two new plants and existing composting facilities. Future estimates reflect projected growth in composting operations, full use of existing plants’ capacity, and the completion of industrial uses currently in the planning or construction stage.

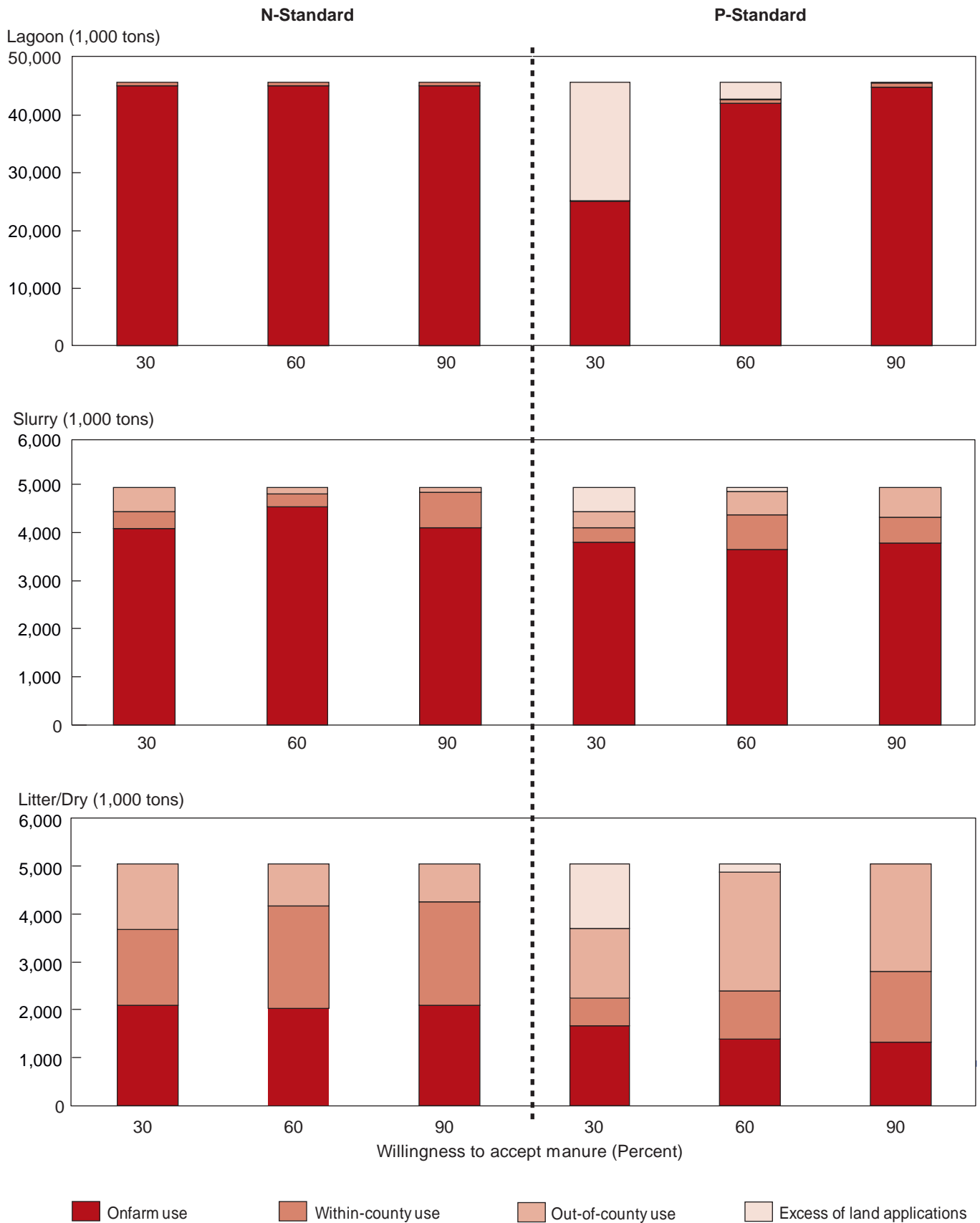
Diverting poultry litter to industrial uses would reduce total land application costs under an N-standard in the CBW by \$2-\$3 million per year in the near term, and \$3.6-\$4.8 million per year as additional projects are completed, for a total drop in regional costs of 5-6 percent depending on the WTAM level. Processing litter into fertilizer and energy would reduce total regional costs by \$10-\$15 per ton, mostly due to savings in off-farm transport and land application. However, factoring in the value of nutrients in manure not going to the land, savings are reduced to \$0.55-\$5.75 per ton (table 4-2).

Under the more stringent P standard, total land application costs would decline by \$4.6 million to \$7.3 million (3 to 4 percent) per year depending on the quantity of poultry litter diverted to industrial facilities at the

¹³ Quantity estimates of poultry litter production based on the Agricultural Census are 710,000 tons in the Delmarva area (Lichtenberg et al., 2002) and 550,000 tons in the Shenandoah Valley (Pelletier et al., 2001).

Figure 4-8

Disposition of manure in the Chesapeake Bay Watershed, by manure handling system and willingness-to-accept, 1997



90-percent WTAM level. Processing litter into fertilizer and energy would reduce total costs by \$20-\$23 per ton, from savings in transport and application costs. Net cost savings are \$8-\$11.50 per ton after accounting for the value of manure nutrients no longer being applied to land in the CBW (table 4-3).

The estimates of manure diverted to industrial uses at a WTAM level of 60 percent absorbed enough manure to enable land application of all remaining manure. However, some of the costs actually increase because more manure was applied than without industrial alternatives, and wetter manure is being transported greater distances due to the diversion of poultry litter to industrial options. At the current industrial level, costs increase but the region is able to spread all manure not sent to an industrial alternative at a 60-percent WTAM. With expanded industrial capacity, there was a cost savings of \$7 per ton in transport costs (\$6 considering fertilizer value adjustments). The transport cost savings at a 60-percent WTAM are about half those at 90-percent WTAM, since wetter manure has to travel longer distances.

The capital costs for the PerdueAgriRecycle™ and Harmony Farms Shenandoah Valley (HSV) facilities were \$13.5 million and \$10 million. Using these two industrial operations as a guide, the amortized capital costs were estimated to be \$1.20-\$2.10 per ton of raw litter used, depending upon the type of operation, capital cost, and percent of operating capacity utilized.¹⁴ In comparison, the reduction in net land application costs due to a diversion of manure to industrial uses is estimated at \$0.50-\$5.75 per ton with the N-standard and \$8-\$33 per ton with a P-standard, depending on the WTAM level.

Our analysis thus indicates that the use of industrial options in the CBW can reduce aggregate manure disposition costs by offering an alternative to hauling manure over greater distances. Animal producers would benefit by not having to incur application costs, and may pay reduced hauling costs. Unless enough industrial capacity was built to use more than the excess amount of manure, crop producers would still need to use the same amount of manure nutrients. Land application cost savings varied considerably with the assumptions made regarding the nutrient standard and willingness to accept manure, but in general they are large enough to warrant further investigation of industrial options. We estimated the potential savings

in net land application costs to be nearly \$2 million with an N-standard and \$3 million with a P-standard (tables 4-2, 4-3).

While this study does not address whether the industrial operations will be profitable and become viable over the long term (data on variable costs for industrial uses were not available), the analysis indicates that the annualized cost of building industrial facilities is often less than the cost of applying manure to land, particularly when meeting a P-standard. While projected industrial use of manure represents less than 1 percent of total CBW manure, potential savings could greatly benefit areas with concentrated animal production and inadequate land for manure application.

Supply-Reducing Technology

Supply-reducing technology is designed to reduce the amount of nutrients excreted in manure, primarily through modification of the diet fed to livestock and poultry.¹⁵ The potential for changing animal diets to reduce nutrient outputs and helping to alleviate potential pollution from nitrogen and phosphorus is widely recognized (CAST, 2002) (see box, “Reducing Manure Nutrients Through Feed Management,” p. 19). Possibilities for improving dietary efficiency and reducing nutrient excretion include substituting phytase and synthetic amino acids for other dietary components.

Using the regional model, we estimate the impact of adding phytase to broiler and swine rations on the costs of applying manure to land under a P-standard. Based on the literature, we assumed the addition of phytase to all swine and poultry diets in the CBW would reduce the phosphorus content of their manure by 30 percent.

The addition of phytase to poultry and swine diets with a 90-percent WTAM, where all manure can be applied to land, reduces the regional costs of manure management, transport, and application by almost \$7 million per year (5 percent of no-phytase costs), with almost 70 percent of the savings in reduced transport costs. Net land application costs would decline by about 4 percent (table 4-3).

At a 60-percent WTAM, adding phytase enables the region to achieve a P-standard, given the land available and the model’s transportation limits. Since the

¹⁴ These estimates assume a capital cost of \$10-\$14 million, a life of 20 years, and an interest rate of 10 percent.

¹⁵ Other supply-reducing alternatives include adjustment in mix of animals or changes in genetic stock.

Industrial Processes for Using Manure

Concerns over increased supplies and concentration of livestock and poultry manure have resulted in numerous proposed manure management solutions beyond land application. However, many of these proposed solutions are still theoretical or experimental. The feasibility of industrial processing varies between livestock species due to differences in manure composition and handling characteristics. Within the Chesapeake Bay watershed, the development of industrial options has been encouraged by the concentration of poultry production and the resulting manure that is relatively dry and amenable to industrial processes.

Several small-scale composting and other processes have been used in the Chesapeake Bay watershed for some time, but only recently have two large-scale industrial solutions for poultry litter have only recently become operational realities. Additional information on alternative uses of poultry litter and other manure is available elsewhere (Lichtenberg et al., 2002; Christensen, 1999).

Perdue AgriRecycle™

Several processes have been developed to make the nutrients and organic matter in manure more uniform, manageable, and marketable. One of these uses a pelletizing technology and process developed by AgriRecycle¹ to transform raw poultry litter into value-added organic fertilizer. This process was implemented through a joint venture with Perdue Farms as a way to manage surplus poultry litter in the Delmarva area. Perdue AgriRecycle™ began operations in 2001 in Suffolk County Delaware, the largest broiler-producing county in the U.S. The plant's capacity is 94,000 tons of litter annually, with permits to expand to 150,000 tons as markets for final product develop. The final product is a pasteurized organic fertilizer granule or pellet, with a nutrient blend (phosphorus, nitrogen, potassium ratio) of 3-4-3, especially designed for precision agriculture applications. It is a certified organic fertilizer, approved by the Organic Materials Review Institute for organic crop production.

Harmony Farms Shenandoah Valley

Harmony Farms Shenandoah Valley (HSV), in Harrisonburg, VA, uses a fertilizer manufacturing technology to convert litter, primarily turkey litter, into energy and an enriched granular product that can be readily transported and applied to land. The process uses a gasification technology that produces thermal energy, coupled with a mixing and blending process using a liquid urea binder. The HSV plant capacity is about 60,000 tons of litter annually. About 10-15 percent of the incoming poultry litter is used to generate energy to run the plant. The remainder is processed and blended with commercial nutrients to produce enriched organic fertilizers for the golf course, landscape, and home garden markets with the nutrient blends varying from 5-5-3 to 14-3-6.

Large-Scale Use of Manure as Biomass Fuel

Manure can be used as a biomass fuel to generate electricity. However, the high moisture content of the manure is a limiting factor. The English company Fibrowatt Limited has proposed to build a large-scale power plant in the Delmarva area similar to what they built in England. The plant would burn biomass (poultry litter and wood products) to produce electric power and a granular fertilizer product from the ash. The proposal has not been accepted for the Delmarva area, primarily because of the high capital and production costs. Energy from litter is estimated to cost 3-4 times the energy from conventional power plants.² Even so, Fibrowatt is designing and building a smaller plant in Minnesota to generate power from turkey litter.

¹ No endorsement of any of these processes or commercial entities by USDA is implied.

² Broiler litter has about half the caloric value of coal.

model shifts from a “no-phytase” alternative with 154,000 tons of excess manure to a “with-phytase” case with all manure applied to land, the cost savings are difficult to interpret. While the total costs of manure management, transport, and application decline by about 3 percent of the no-phytase costs, net land application costs declined about 11 percent, or

\$10 million. The application of manure that could not be spread under the P-standard case increased the chemical fertilizer savings with phytase. The manure management, transport, and application cost savings would have been greater if not for the additional 154,000 tons of manure that can be land applied with phytase. Clearly, the use of supply reduction technolo-

Table 4-2—Total and net land application costs to meet an N-standard in the Chesapeake Bay Watershed, by willingness-to-accept-manure and level of industrial use

Cost category	N-standard	Current industrial (CI)	Expanded industrial (EI)	Changes from N-standard (CI)	Changes from N-standard (EI)	Changes per ton (CI)	Changes per ton (EI)
WTAM = 90 percent							
Transport costs	79.65	78.16	77.14	1.49	2.51	7.49	6.68
Application/incorporation costs	33.61	33.01	32.54	0.60	1.07	3.02	2.85
Management costs	10.5	10.48	10.47	0.02	0.03	0.10	0.08
Total land application costs	123.76	121.65	120.15	2.11	3.61	10.60	9.60
Less: Chemical fertilizer savings	-67.55	-65.55	-64.24	-2.00	-3.31	-10.05	-8.80
<i>Net land application cost</i>	<i>56.21</i>	<i>56.10</i>	<i>55.91</i>	<i>0.11</i>	<i>0.30</i>	<i>0.55</i>	<i>0.80</i>
WTAM = 60 percent							
Transport costs	83.08	81.33	80.04	1.75	3.04	8.79	8.09
Application/incorporation costs	33.59	33.07	32.75	0.52	0.84	2.61	2.23
Management costs	10.45	10.44	10.44	0.01	0.01	0.05	0.03
Total land application costs	127.12	124.84	123.23	2.28	3.89	11.46	10.35
Less: Chemical fertilizer savings	-64.45	-62.70	-61.6	-1.75	-2.85	-8.79	-7.58
<i>Net land application cost</i>	<i>62.67</i>	<i>62.14</i>	<i>61.63</i>	<i>0.53</i>	<i>1.04</i>	<i>2.66</i>	<i>2.77</i>
WTAM = 30 percent							
Transport costs	88.19	86.18	84.76	2.01	3.43	10.10	9.12
Application/incorporation costs	35.01	33.96	33.61	1.05	1.40	5.28	3.72
Management costs	10.43	10.42	10.42	0.01	0.01	0.05	0.03
Total land application costs	133.63	130.56	128.79	3.07	4.84	15.43	12.87
Less: Chemical fertilizer savings	-62.55	-60.62	-59.74	-1.93	-2.81	-9.70	-7.47
<i>Net land application cost</i>	<i>71.08</i>	<i>69.94</i>	<i>69.05</i>	<i>1.14</i>	<i>2.03</i>	<i>5.73</i>	<i>5.40</i>

Table 4-3—Total and net land application costs to meet a P-standard in the Chesapeake Bay Watershed, by willingness-to-accept-manure, level of industrial use, and addition of phytase to feed

Cost category	N-standard	Current industrial (CI)	Expanded industrial (EI)	Phytase	Changes from N-standard		Changes per ton	
					(CI)	(EI)	(CI)	(EI)
WTAM = 90 percent								
Transport costs	91.51	88.37	86.60	87.36	3.14	4.91	15.78	13.06
Application/incorporation costs	41.39	40.01	39.10	39.04	1.38	2.29	6.93	6.09
Management costs	11.41	11.34	11.27	11.17	0.07	0.14	0.35	0.37
Total land application costs	144.31	139.72	136.97	137.57	4.59	7.34	23.07	19.52
Less: Chemical fertilizer savings	-68.38	-66.08	-63.97	-67.30	-2.3	-4.41	-11.56	-11.73
Net land application cost	75.93	73.64	73.00	70.27	2.29	2.93	11.51	7.79
Excess manure (1000 tons)	0	0	0	0				
WTAM = 60 percent								
Transport costs	102.04	103.72	99.24	97.07	-1.68	2.80	-8.44	7.45
Application/incorporation costs	39.52	40.53	39.85	39.48	-1.01	-0.33	-5.08	-0.88
Management costs	11.24	11.24	11.19	11.10	0	0.05	0.00	0.13
Total land application costs	152.80	155.49	150.28	147.65	-2.69	2.52	-13.52	6.70
Less: Chemical fertilizer savings	-61.77	-63.09	-61.62	-66.63	1.32	-0.15	6.63	-0.40
Net land application cost	91.03	92.40	88.66	81.02	-1.37	2.37	-6.88	6.30
Excess manure (1,000 tons)	154	0	0	0	-154	-154	-154	-154

\$ Million

gy has greater potential for cost savings at lower WTAM levels.

Phytase also significantly reduces the amount of excess manure at lower WTAM levels. At 30-percent WTAM, the use of phytase reduced the manure in excess of land application capacity by about 45 percent, enabling an additional 500,000 tons of manure to be spread.

Summary

Management of livestock manure is crucial to the Chesapeake Bay watershed (CBW), given its concentration of animal production and the State/Federal commitment to protect the bay's resources. New policies on the handling of animal manure are likely to have a significant impact on the livestock and poultry sectors. This is particularly true in the CBW, where counties rank among the highest in the Nation in concentrations of surplus manure nutrients.

The willingness of crop producers to accept manure on eligible acres is an important consideration. In fact, our results indicate that this could be the most important consideration in determining whether land application as a stand-alone strategy is feasible in the CBW. We find that, at willingness-to-accept-manure (WTAM) levels of 60 percent or lower, there is an insufficient land base to apply all the manure under a P-standard, given the modeled transportation radius and no change in land use, crop mix, or animal location. Similarly, all manure cannot be land applied under an N-standard at WTAM levels of 20 percent or lower. Current data suggest that between 10 and 20 percent of cropland receives manure.

Holding animal production constant, the estimated total cost for land application of manure was \$123 million to \$155 million per year over the set of solutions in which all manure may be land applied. This is a high proportion of annual total net returns to animal production in the CBW (\$313 million). The model cannot estimate land application costs when long-distance hauling would involve transporting the manure beyond the modeled transportation radius of roughly 150 km. Over 60 percent of manure disposition costs were for transport, and less than 30 percent for application/incorporation. By location, **onfarm** hauling and distribution of manure accounted for up to 75 percent of the total costs, but the costs tended to be constant in dollar amount over the range of WTAM levels where all manure could be land applied. Most of the cost increases from reduced WTAM levels were associated with **off-farm** movement of manure. Out-of-county transportation, application, and incorporation

costs were estimated to range between \$9 million and \$55 million, depending on which nutrient standard was in effect and the willingness of crop producers to accept manure.

The net costs of manure management in the CBW depend not only on the total land application cost but also on the potential savings in commercial fertilizer by more efficiently using manure nutrients, as well as on the costs of addressing the manure that could not be land applied due to model transportation limits. The potential savings in commercial fertilizer purchases and application costs were estimated at \$60-\$68 million, which offset 40-55 percent of the total costs of applying manure to land. The extent to which the potential nutrient savings are translated into farm returns will influence not only the net manure disposal costs but also a producer's willingness to accept manure. Moreover, some portion of those savings will be felt as reduced revenues to fertilizer suppliers.

Finally, significant quantities of manure under the P-standard were not land applied in our modeling framework at many WTAM levels. The disposition of this manure remains a challenge, perhaps an expensive challenge, for manure management in the CBW.

The annual cost savings from shifting manure from land application to industrial uses compare favorably to the annualized capital costs of recently constructed industrial litter processing facilities. A P-standard issued cost savings of \$2-\$7 million by shifting manure to an industrial plant rather than hauling it to a distant site for land application, depending on the region's willingness to accept manure for land application. These cost savings are concentrated primarily in areas with high animal numbers and limited land for manure application. Similarly, the addition of phytase to the diet of swine and poultry reduced land application costs by \$6-\$10 million. Phytase also enables the application of much more manure to the region's land base, particularly important for meeting a P-standard when WTAM is not high. These preliminary values provide a starting point for an indepth investigation of industrial options and their potential for the CBW's agricultural economy.

The need to transport manure over longer distances has structural implications for the agricultural sector. Moving manure to a location that is miles away from the manure source presumes that a marketing structure is in place and that a consistent, standardized product is shipped to the destination. It is likely that a more formal marketing system will develop over time to satisfy this need, spurred on by the new policy.

Appendix 4-A

Modeling Manure Management in the Chesapeake Bay Watershed

The model is designed to minimize total regional costs of applied manure, including manure transport, land application, and selected nutrient management plan costs in the Chesapeake Bay watershed, given 1997 animal production levels. The model was developed to (1) provide a mechanism that tracks manure and related nutrient flows within the watershed, from manure source to site application and use, (2) estimate the regional costs of applying manure to land, and (3) provide a framework for evaluating proposed land-application regulations and alternative nutrient management policies. The regional model specification captures the competition for land on which to spread manure by endogenizing access to spreadable land and associated hauling costs. Explicit modeling of competition for land in areas with significant animal concentrations is a central feature of the regional model that is not reflected in existing farm-level models.

Regional Model Structure

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 county-level data, while permitting differentiation in animal production, nutrient uptake, waste technologies, institutions, and regulatory conditions across county and State boundaries within the watershed.

Manure is produced in a “source” county (ct) and land applied (or otherwise disposed of) in a “destination” county (ct2). “Model” counties include 160 non-municipality counties with farmland in the Chesapeake Bay watershed. “Sink” counties refer to destination counties outside the modeled area that could serve as potential destinations for manure exported from the watershed. Model counties may be both source and destination counties; sink counties are destination counties only. The potential level of out-of-basin exports depends on net assimilative capacity of the sink counties after accounting for county manure applications. There are 104 sink counties included in the full watershed model, comprising non-municipality counties within 60 kilometers (37 miles) of cropland in a model county. Model solution values for “edge” counties, or those that straddle the watershed boundary, are apportioned by share of farmland within the watershed to more accurately account for manure disposition at the basin level.

The optimization model is designed to minimize the regional cost of applied manure, subject to total manure produced, land availability for manure applications, and other disposal options. The model allocates manure flows across the watershed and neighboring sink counties to minimize the objective function expression:

$$(1) \sum_{ct} \sum_{ct2} [HAC_{ct, ct2} + NM1_{ct} + NM2_{ct2} + ELA_{ct} - FS_{ct2}]$$

Costs include manure hauling and application costs (HAC), land incorporation costs (INC), and nutrient management plan charges for source (NM1) and destination (NM2) counties. A penalty cost for manure levels exceeding land application (ELA) capacity is included to ensure that all manure is land applied subject to available land (this cost is removed from reported costs). Aggregate costs are further adjusted to reflect cost savings from reduced purchase and application costs for chemical fertilizers (FS).

In-county and out-of-county transfers of manure are the primary activities in the model. Potential county-to-county transfers were developed based on an assumed maximum radial distance of 60 kilometers (37 miles), or 150 kilometers (93 miles) for the largest manure-surplus counties (10 percent of total), measured from the outer edge of the source county’s cropland base. There are 4,060 county-level transfer possibilities in the full watershed model, including in-county and out-of-county transfer combinations. Manure transfers are further disaggregated by sub-county grid location, manure system type, and distance interval, resulting in over 300,000 transfer alternatives.

The primary decision variables in the model represent the quantity of manure transferred (M_TRN), acres used for manure spreading (AC_SPR), and manure hauling distance (DST). Model equations include (1) balance equations that track stocks and flows of manure and manure nutrients, (2) constraints on land availability, distribution of confined animal farms (manure sources), and manure nutrient use, and (3) cost accounting equations. In general, wet manure quantities form the basis of model hauling and application costs, while manure nutrient content and uptake rates determine the volume and direction of manure flows.

Primary manure transfer equations are as follows:

$$(2) \quad M_TRAN_{ct, ct2} = ((M_AP_{ct, ct2, N} * SH_N_{ct2}) + (M_AP_{ct, ct2, P} * (1 - SH_N_{ct2}))) * AC_SPR_{ct, ct2}$$

$$(3) \quad \sum_{ct} AC_SPR_{ct, ct2} \leq A_{ct2} * WTA_{ct2}$$

$$(4) \quad M_TRN_{ct, ct2} = \sum_{gr} \sum_{sv} \sum_{ds} M_TRN_{ct, gr, ct2, sy, ds}$$

$$(5) \quad \sum_{ds} M_TRN_{ct, gr, ct2, sy, ds} \leq M_PRD_{ct, ct2} * SH_M_{ct, gr, ct2, sy}$$

where N^* represents N-standard and P^* represents P-standard, gr is county grid location, sy is manure system (lagoon, slurry, dry; see box, “Manure Handling Systems,” p. 47), and ds is hauling distance interval in miles. Onfarm hauling distance is set based on estimated average county distance. Off-farm hauling distance is derived endogenously, falling within one of three intervals (0.5-2, 2-10, >10) used to calculate hauling costs.

In Equation (2), dry manure tons by county transfer (M_TRAN) is defined as the product of per acre manure application rate (M_AP) by county transfer—weighted by the acreage share under an N-standard (SH_N) and acreage share under a P-standard ($1 - SH_N$)—and receiving acres (AC_SPR) in the destination county. Manure application rate is estimated for each individual in-county and out-of-county transfer, based on: (1) average nutrient content of manure from the source county; (2) average nutrient removal rates for N and P in the destination county, weighted across cropland and pastureland for each of three farm types (non-animal farms, non-confined animal farms, and confined animal farms); (3) nitrogen volatilization factors, with and without incorporation; and 4) the nutrient standard in effect.¹⁶ Data specification by county and farm type allows the model to capture potential variation in assimilative capacity due to differences in cropping pattern, land in pasture, and crop yield.

Equation (3) restricts applied manure from all potential source counties to total spreadable acreage (A) in the destination county. Assumptions on land operator willingness to accept manure (see box, “Willingness to Accept Manure,” p. 21) are reflected in automated adjustments in both the quantity of spreadable acreage and slope of “area-to-distance” functions, or hauling distance required to access a given spreadable area. Values for levels of willingness to accept manure on non-animal farms and nonconfined animal farms range from 10 percent to 100 percent; all acreage on confined animal farms is assumed available for manure spreading. Equation (4) sets aggregate county-level manure transfers (M_TRAN) equal to the sum of manure transfers by source-county grid location (gr), system type (sy), and distance interval (ds). Equation (5) bounds manure transfers by the share (SH_M) of total county-level manure production (M_PRD) across system type (sy) and grid (gr), based on allocation procedures followed in the GIS.

Equations (6) through (8) are used to balance manure production, use, surplus, and quantity of manure exceeding land application capacity at the county level.

$$(6) \quad M_SRP_{ct} = M_PROD_{ct} - M_ONFRM_{ct}$$

$$(7) \quad M_USE_{ct2} = M_ONFRM_{ct2} + \sum_{ct2} M_TRAN_{ct, ct2}$$

$$(8) \quad M_ELA_{ct} = M_SRP_{ct} - \sum_{sy} M_IND_{ct, sy} - \sum_{ct2} M_TRAN_{ct, ct2}$$

Equation (6) sets surplus manure (M_SRP) as manure production (M_PROD) less that used onfarm (M_ONFRM) in the source county. Equation (7) fixes manure use (M_USE) as onfarm manure use plus that quantity obtained from off-farm sources (M_TRAN) in the destination county. Equation (8) sets the manure that exceeds land application capacity (M_ELA) due to insufficient assimilative capacity within the transport radius equal to the manure surplus in the source county, less the sum of industrial uses (M_IND) and the sum of manure transfers out of county. Manure used for industrial purposes is defined exogenously by county and waste-system type (i.e., dry poultry

¹⁶ Manure application rates may be modified to reflect adjustments in nutrient content (i.e., due to changes in feed supplements or animal mix) and nutrient uptake rates (i.e., due to changes in cropping patterns or yields), as well as county-level acreage shares by nutrient standard, for cropland and pastureland.

litter) and converted to dry-ton equivalents for use in the model. Quantities of ELA manure are minimized in the model through the use of a penalty cost parameter that assigns a high cost to manure that is not land applied.

Hauling distances are computed based on Equations (9) – (11).

$$(9) \quad DS_{ct, gr, ct2} = \{(\alpha_{ct, gr, ct2} * \delta^1_{ct, ct2}) + (\beta_{ct, ct2} * (AC_ONF_{ct} + \sum_{ct} AC_SPR_{ct, ct2}))\} * \delta^2_{ct2}$$

$$(10) \quad DS_{ct, gr, ct2} * M_TRN_{ct, gr, ct2} = \sum_{sy} \sum_{ds} (DST_{ct, gr, ct2, sy, ds} * M_TRN_{ct, gr, ct2, sy, ds})$$

$$(11) \quad D_MN_{ds} \leq DST_{ct, gr, ct2, sy, ds} \leq D_MX_{ds}$$

In Equation (9), average hauling distance (DS) from source county (*ct*) and grid location (*gr*) is calculated as a function of onfarm and off-farm spreadable acres in the destination county (*ct2*), based on α and β coefficients from the GIS-derived linear regression estimates. The intercept term, representing linear hauling distance from the source farm for out-of-county transfers, is adjusted (δ^1) for selected county-to-county transfers due to natural barriers (e.g., large bodies of water). In addition, a circuitry parameter (δ^2) is used to convert linear distance to road miles (USDC, 1978). In Equation (10), average hauling distance represents a weighted average of hauling distances (DST) by manure-system type (*sy*) and distance interval (*ds*). Minimum (D_MN) and maximum (D_MX) distance is specified by distance interval in Equation (11).

Stocks and flows of manure nutrients (*np*)—nitrogen (*n*) and phosphorus (*p*)—are tied to manure quantities as follows:

$$(12) \quad M_SRP_{ct} = NP_EXC_{ct, np} / NP_M_{ct, np}$$

$$(13) \quad NP_ONF_{ct2, np} = M_ONFRM_{ct2} * NP_M_{ct, np} \text{ where } ct = ct2$$

$$(14) \quad NP_TRN_{ct, ct2, np} = M_TRAN_{ct, ct2} * NP_M_{ct, np}$$

Total excess nutrients (NP_EXC) are obtained from farm-level Census data on manure production and onfarm assimilative capacity aggregated to the county level. Equation (12) calculates surplus manure (M_SRP) based on excess N or excess P, depending on the nutrient standard in effect (*N** or *P**) and county-average nutrient content per dry ton of manure (NP_M). In Equation (13), onfarm manure nutrients (NP_ONF) reflect the quantity (M_ONFRM) and composition of manure produced and used on confined animal feeding operations. In Equation (14), manure nutrients transferred (NP_TRN) reflects manure land-applied off the farm.

$$(15) \quad HAC_{ct, ct2} = \sum_{gr} \sum_{sy} \sum_{ds} [C1_{sy, ds} + (C2_{sy, ds} * DST_{ct, gr, ct2, sy, ds})] * M_TRN_{ct, gr, ct2, sy, ds} / (1 - (MS_{sy} + BED_{sy}))$$

$$(16) \quad INC_{ct2} = (C3 * SH_I_{ct2} * (AC_ONF_{ct2} + \sum_{ct} AC_SPR_{ct, ct2}) * SH_C_{ct2})$$

In Equation (15), manure hauling and application costs (HAC) are computed for onfarm and off-farm transfers based on loading, unloading, and application costs per ton hauled (C1), hauling cost per ton-mile (C2), distance hauled (DST), and quantity of manure hauled in dry tons (M_TRN), adjusted for moisture content (MS) and bedding (BED). Hauling and application costs vary across animal-waste systems due to differences in manure moisture content and equipment used, by species and system type. The model simulates a stepwise cost function for manure hauling/application cost, with cost coefficients defined by manure system type and distance interval hauled. Incorporation costs (INC) (incorporating manure into the soil) are computed in Equation (16) based on per acre cost (C3), share of acres incorporating (SH_I), total onfarm and off-farm acres using manure, and share of acres in cropland (as manure is not generally incorporated on pastureland).

$$(17) \text{ NM1}_{ct} = (\text{M_TST} + \text{C_NMP}) * \text{AFO}_{ct}$$

$$(18) \text{ NM2}_{ct2} = \text{S_TST} * (\text{AC_ONF}_{ct2} + \sum_{ct} \text{AC_SPR}_{ct, ct2})$$

Selected nutrient management plan costs related to land application are identified for manure source farms and receiving farms. Equation (17) computes source-county costs (NM1) for manure testing and plan development costs, based on a representative cost (M_TST and C_NMP) applied to the number of confined animal-feeding operations (AFO) in the source county. Equation (18) computes destination county costs (NM2) for soil testing, based on representative costs (S_TST) per acre of land receiving manure.¹⁷ Structural costs associated with manure processing and storage are not considered in this study, although capital costs to improve manure storage and handling may be required to accomplish the extent of land application addressed in the study.

$$(19) \text{ FSV}_{ct2, N*} = (\text{PR}_n * (\text{NP_ONF}_{ct2, n} + \sum_{ct} \text{NP_TRN}_{ct, ct2, n})) \\ + (\text{PR}_p * (\text{NP_ONF}_{ct2, p} + \sum_{ct} \text{NP_TRN}_{ct, ct2, p})) * \text{P_PCT}_{ct2} \\ + (\text{C_AP} * (\text{AC_ONF}_{ct2} + \sum_{ct} \text{AC_SPR}_{ct, ct2}))$$

$$(20) \text{ FSV}_{ct2, P*} = (\text{PR}_n * (\text{NP_ONF}_{ct2, n} + \sum_{ct} \text{NP_TRN}_{ct, ct2, n})) \\ + (\text{PR}_p * (\text{NP_ONF}_{ct2, p} + \sum_{ct} \text{NP_TRN}_{ct, ct2, p}))$$

$$(21) \text{ FS}_{ct2} = (\text{FSV}_{ct2, N} * \text{SG_N}_{ct}) + (\text{FSV}_{ct2, P} * (1 - \text{SH_N}_{ct}))$$

Fertilizer cost savings (FSV) are calculated differently, depending on the nutrient standard in effect. In Equation (19), savings calculated under an N-standard reflect (1) reduced chemical fertilizer purchases, computed based on the price (PR) of nutrients N and P and the quantity of manure nutrient offset—adjusted to capture that portion of P (P_PCT) that is beneficially used by the crop over the growing season, and (2) savings from reduced field application costs, as applied manure satisfies the full crop-nutrient requirement. In Equation (20), savings calculated under the P-standard reflect the value of the manure nutrient offset only; field application costs for chemical fertilizer are required as manure-N is insufficient to meet full crop needs.¹⁸ Equation (21) computes an acreage-weighted fertilizer cost savings (FS), based on the share of acres permitted to land-apply manure at the less-stringent N-standard.

Model Data

The Chesapeake Bay Watershed model relies on two primary data sources: the 1997 Census of Agriculture and the National Land Cover Dataset from the U.S. Geological Survey (USGS). Farm-level Census data are 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 animal operations. Cost data and other information reflecting conditions in the CBW/Mid-Atlantic region were obtained from various sources, including the USDA's Natural Resources Conservation Service (NRCS) Cost and Capabilities Assessment (USDA, NRCS, 2003), ARMS data (USDA, ERS, 2002a), published literature, and subject matter specialists within the government and various universities.

¹⁷ Nutrient management plan costs involving record keeping and visual inspection were not specifically related to manure land application, and were not addressed here. Costs for training and certification for manure application, and calibration of manure spreader, were assumed to be incorporated within reported application costs per ton of manure hauled.

¹⁸ For purposes of this analysis, it is assumed that chemical nutrients are applied at strict agronomic rates, that manure nutrients directly offset nutrients obtained from chemical fertilizers, that per-acre field application costs are fixed regardless of the level of applied chemical fertilizer, and that producers are not permitted to "bank" phosphorus (over-apply for use over multiple years) to minimize annual field application costs under the P-standard. A multi-year P-standard, permitted by NRCS under certain soil conditions, may be modeled by adjusting for savings in the application cost of chemical fertilizer during the treatment year of a multi-year manure rotation.

Using data collected for the 1997 Census of Agriculture (USDA, 1999), we estimate manure-nutrient surpluses by applying farm-level measures of manure-nutrient production relative to the farm's potential to use nutrients for crop production. For modeling purposes, results from the farm-level calculations are aggregated to the county level.¹⁹ Manure-nutrient production, potential manure nutrient use by farms with animals, surplus recoverable manure nutrients, and potential assimilative capacity of farms by farm type are computed following procedures in Gollehon et al. (2001) and Kellogg et al. (2000). Manure-nutrient production—nitrogen and phosphorus—is estimated using Census-reported end-of-year inventory and annual sales data, based on coefficients of manure production by animal type. Additional information on manure system shares by animal type is obtained from ARMS data (USDA, ERS, and 2000b). Nutrient content of manure reflects a composite nutrient content by county, based on county-level distributions of animal species from the Census of Agriculture. Potential manure-nutrient use is estimated across farm types based on reported yields and acreage for 24 major field crops and pasture. Excess recoverable manure nutrients are calculated as those that exceed the onfarm assimilative capacity of confined feeding operations, based on the amount of land controlled by the farms with the animals.

The farmland base available for surplus manure spreading is defined in the model to include all cropland and pastureland on non-animal farms and some portion of acreage on nonconfined animal operations (adjusting for nonrecoverable N available) and confined animal operations (from those farms with surplus acreage capacity). The model incorporates adjustments in total farmland base to reflect alternative assumptions on the willingness of landowners to accept manure, expressed as a share of total acreage (10 to 100 percent). Other land-adjustment factors not explicitly addressed in the model—including crop-type considerations, stream buffer provisions, and use of municipal sludge—may also affect availability of land for manure spreading. Crop and pastureland acreage in sink counties is assumed available for manure from the watershed, after adjusting for application of locally produced manure within the sink county.

Manure-hauling weights are based on dry tons of manure, adjusted for moisture and bedding content by manure system and species type (USDA, NRCS, 1999c; Barker et al., 2001) (see box, “Manure Handling Systems,” p. 47). Manure application rates are calculated based on manure-nutrient composition (source county) and aggregate nutrient uptake (destination county) from Census calculations (USDA, NRCS, 1999c). Separate onfarm application rates are derived for confined animal farms, reflecting differences in cropping patterns and yields.²⁰ Since reliable data on the share of land likely to adhere to a phosphorus standard are not available, model scenarios are specified as if all acres would apply manure according to an N-standard or to an annual P-standard, thus covering the full range of possible results (see box, “Nutrient Standards,” p. 38).

Spatial Land and Distance Data

To assess the spatial pattern of spreadable land for manure application, we use the USGS National Land Cover Dataset. This dataset is based on 1992 Landsat thematic mapper imagery at 30-meter resolution, classified into 21 land-use categories. By combining cropland and pastureland categories, we capture the spatial distribution of the spreadable land base for counties within the study region.

To estimate hauling-distance requirements for off-farm manure spreading, a GIS creates “area-to-distance” functions for each county and county-to-county transfer in the CBW.²¹ These functions are a central component of the optimization model, linking the area used for manure spreading in the destination county with the average transport distance required to reach all of the land.

The number, location, and size of confined animal operations will influence the degree of competition for available acreage on which to spread manure. With greater concentrations of animal production, the nearby spreadable acreage is more fully used, resulting in increasing transport distances and greater potential for out-of-county manure exports. The number and average size of confined feeding operations is available by county from the

¹⁹ Our analysis meets all respondent confidentiality requirements of the published Census of Agriculture values.

²⁰ Model application rates assume a base nitrogen adjustment due to normal field loss of 30 percent. This base N loss factor is further adjusted downward by 5 percent for systems with soil incorporation and 30 percent for systems without incorporation (Fleming et al., 1998, and Kellogg et al., 2000).

²¹ Onfarm hauling distances by county are fixed in the model based on data obtained through the NRCS Cost and Capabilities Assessment (USDA, NRCS, 2003).

Census, although the specific location of these operations within the county is unknown. Using the GIS, animal operations are randomly assigned by county grid location within cropland and pastureland areas of the county.²²

Area-to-distance functions are estimated for all in-county and out-of-county transfer possibilities in the model, based on the spatial relationship between manure source and the location and density of spreadable area. In-county transfers reflect the average hauling distance from confined feeding operations within a given county to spreadable land in that county, both onfarm and off-farm. With small amounts of surplus manure, spreadable land is relatively accessible and hauling distances are generally short. As surplus manure increases, so, too, does the land needed for spreading manure, increasing the transport distance to access needed acreage.²³ Depicted graphically, the relationship between the spreadable acreage requirement and average distance hauled is upward sloping and fairly linear along much of the observed range (fig. 4-A-1).

Out-of-county functions reflect hauling distances for confined feeding operations in the source county to spreadable acreage in the destination counties. A two-stage process is used to generate area-to-distance functions for out-of-county transfers. First, distance is measured from each confined animal farm in a source county to the edge of spreadable acreage in a destination county; this distance represents the intercept term of the area-to-distance function. Second, the slope of the distance function is generated by calculating hauling distance required for a given area of spreadable acreage in the destination county, measured from the direction of the source county.

The slope of the area-to-distance functions reflects the spatial pattern of farmland relative to the number and location of confined feeding operations from a given source county. Competition for spreadable land is, in part, a function of the spatial distribution of cropland and pastureland. Where farmland is scattered, a higher slope coefficient reflects relatively long average hauls within the destination county to access a given spreadable area. Where farmland distribution is more dense, a lower slope coefficient reflects comparatively shorter hauls to access a given acreage. The degree of competition will depend on both spatial distribution of the spreadable land base and the quantity and proximity of competing manure sources across counties.

Integration of GIS data within the optimization framework represents a key component of the model. Regression coefficients for the area-to-distance functions are incorporated as model parameters for within- and out-of-county transfers. A unique set of slope coefficients is produced for each within-county function and for each county-to-county transfer, representing distance hauling requirements within the destination county. In addition, out-of-county functions involve separate intercept terms by source farm-grid location for every possible destination-county option, representing linear distance from the farm to the edge of the landbase within the destination county. County-to-county transfer possibilities include all counties within an assumed 60-kilometer (km) radius of a given source county; the radius for source farms in the 16 counties with highest concentrations of surplus manure was expanded to 150 km (93 miles).²⁴ To reduce the number of manure source and destination combinations, animal operations were aggregated (binned) into 12-km grids across the watershed area. Although the binning procedure reduces the precision of intercept terms for intercounty functions, this was necessary to keep the model optimization reasonably within the bounds posed by our computer hardware. In addition, the distance functions estimated from the GIS are linearized for modeling purposes by truncating the upper and lower tails of the distribution (10 percent of acreage respectively) and fitting a linear function to the nearly linear 80 percent of the midrange observations (fig. 4-A-1).

Production Cost Data

The NRCS Cost and Capabilities Assessment was the primary source of cost data for nutrient management plan components (USDA, NRCS, 2003). Cost components for manure management addressed in this study include nutrient management planning (\$1.67 per acre receiving manure), manure testing (\$200 per farm), and soil testing (\$0.40 per acre receiving manure).

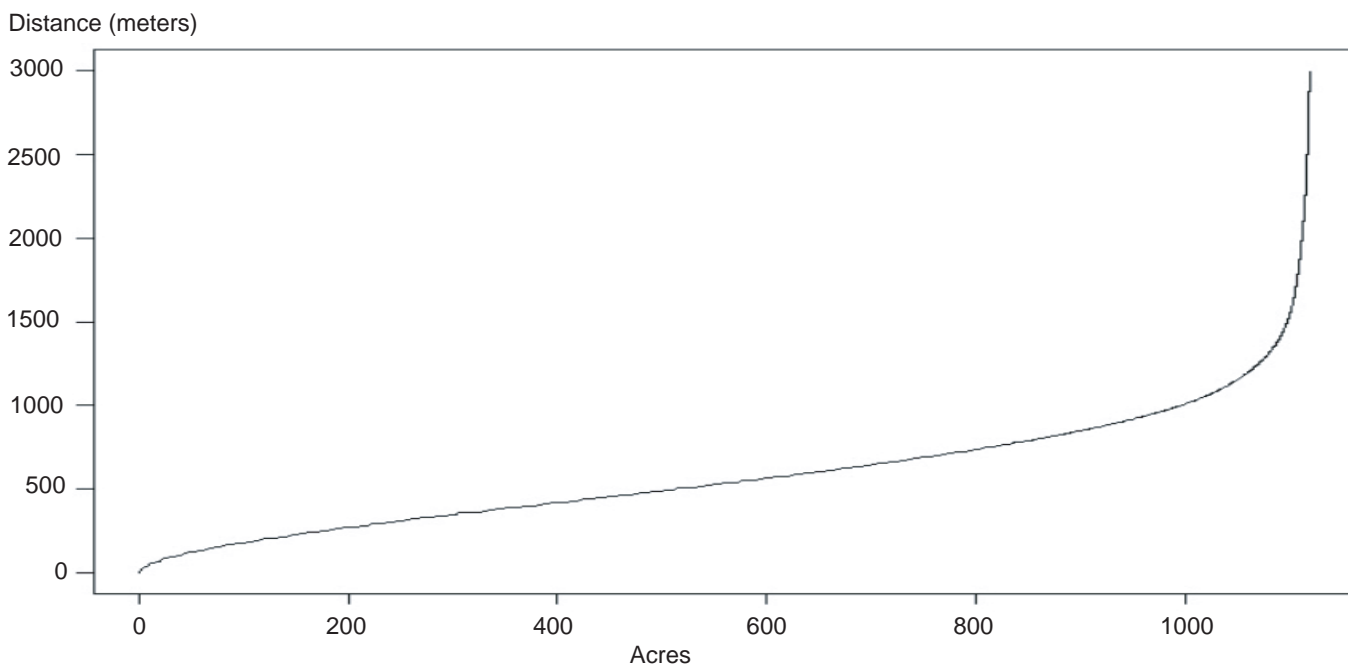
²² Although animal operations may be separated from arable land as animal production is not as sensitive to soil conditions, the majority of operations tend to be located in proximity to cropland and pasture land. While the random farm location assumption is regarded as reasonable at the watershed scale, it likely yields somewhat conservative estimates of actual hauling distances due to observed clustering of animal operations, in some cases increasing competition for adjacent land resources.

²³ The actual area of available spreadable acreage used for manure application in a given county is determined endogenously in the optimization model.

²⁴ Individual hauling distances in the model may exceed the maximum radial distance assumed for county transfer selection (150 km) due to (1) additional hauling requirements within the destination county, and (2) parameters that translate linear distance to road miles. The maximum radial distance assumption of 150 kms could be relaxed but at a cost of model dimensionality.

Figure 4-A-1

Representative area-to-distance function



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 (table 4-A-1).²⁵ Application costs are incorporated within hauling charges for lagoon and slurry systems; an additional charge of \$4.00 was included for dry manure application. Manure incorporation costs assume a cost of \$6.00 per acre (Iowa State Farm Survey, 2001), with 40 percent of acres incorporating regionally based on information from the ARMS hog and dairy surveys.

Chemical fertilizer costs are based on reported 1997 prices by USDA’s National Agricultural Statistics Service (NASS), based on representative fertilizer products for the Northeastern U.S. (USDA, NASS, 2001). Nitrogen price reflects the U.S. average price (\$160 per ton) for a nitrogen solution of 30 percent N, or a price per active ingredient of \$0.27 per lb.-N. (The 30-percent nitrogen solution is selected as a representative form of N because it was the lowest priced form of N with adequate use for NASS to record region prices for both the Northeastern and Southeastern U.S. regions.) Phosphorus price reflects the price per ton of triple superphosphate (45 percent P), averaged across the Northeastern and Southeastern regions (\$267 per ton), or an active ingredient price of \$0.30 per lb.-P. Cost-savings for reduced field application costs (under an N-standard) of \$5 per acre were from Fleming, 1998. While the model provides for the pricing of manure, revenue received for manure is currently set to zero. Prices paid for manure will not affect total regional cost, but would have distributional implications across areas of the watershed.

²⁵ While not addressed in this analysis, adjustments may be incorporated to reflect lower hauling charges with backhauls, public cost-sharing for manure hauling, allocation of costs across manure providers and recipients, and manure pricing.

Table 4-A-1—Manure hauling costs by system type

System type	Distance interval	Hauling mode	Base charge ¹	Distance charge	Distance charge, with backhaul ²
	<i>Miles</i>		<i>\$/ton</i>	<i>\$/mile</i>	<i>\$/mile</i>
Lagoon	onfarm	Pump/spray field	1.25	.25	
	0.5-2.0	Truck mounted liquid sprayer	2.00	.30	
	2.0-10.0	Truck mounted liquid sprayer	2.00	.30	
Slurry	onfarm	Tractor/spreader (honey wagon)	2.00	.30	
	0.5-2.0	Truck mounted liquid sprayer	2.00	.30	
	2.0-10.0	Tanker truck	2.00	.30	
	>10.0	Tanker truck	2.00	.30	
Dry	onfarm	Spreader truck	6.00	.50	
	0.5-2.0	Spreader truck	6.00	.50	
	2.0-10.0	Truck	10.00	.11	
	>10.0	Truck	10.00	.11	.07

¹Includes cost of hauling and unloading. Application costs are reflected for lagoon and slurry manure; an additional application charge of \$4.00 per ton-not reflected in the table-is included in the model for dry manure. Manure incorporation costs are estimated at \$6.00 per acre, with acreage shares set to 40 percent in the base model.

²A cost adjustment for backhauling may be applied to long-distance hauls for dry manure, although the base model assumes 0% backhauling.

Sources: NRCS, 2003; Fleming et al., 1998; Pease et. al., 2001; Borton et al., 1995.