Model Data

The two primary data sources for the model include the 1997 Census of Agriculture and the 1994 National Land Cover Dataset. The 1997 Census of Agriculture was administered by the National Agricultural Statistics Service (NASS), USDA. Primary data processing for this analysis was conducted by the Economic Research Service (ERS), USDA, and Natural Resources Conservation Service (NRCS), USDA. The resulting database provided base model data on animal farms, numbers of animals (used to estimate manure production), and cropped area and production (used to estimate the land assimilative capacity of manure nutrients). The 1994 National Land Cover Dataset, developed by the U.S. Geological Survey (USGS), was used to establish the spatial pattern of land available for manure spreading. The resulting land coverage was used as a basis for developing distance functions for manure hauling and simulating the spatial distribution of animal operations. In addition to the two primary data sources, technology and cost coefficients applicable to the Chesapeake Bay watershed were obtained from various sources, including the Costs Associated with Development and Implementation of Comprehensive Nutrient Management Plans prepared by NRCS (USDA, NRCS, 2003), the Agricultural Resource Management Survey (ARMS) data developed by NASS and ERS (USDA, 2002 and 2000), and additional data obtained from published literature and subject matter specialists within the Government and universities.

Manure-Nutrient Production and Use

Farm-level data collected for the 1997 Census of Agriculture were used to estimate county-level measures of animal operations and animal-units, total manure production, surplus recoverable manure (in excess of source-farm crop need), manure-nutrient content, and potential assimilative capacity of the land for applied manure nutrients (USDA, NASS, 1999). Farm-level measures were computed from the Agricultural Census and other technical data. Results from the farm-level calculations were then aggregated to the county level and combined with data from various other sources for analytic and modeling purposes.[6] Census data coefficients are computed following procedures in Gollehon et al. (2001) and Kellogg et al. (2000).

Animal operations. The analysis focuses on confined animal species since they represent the primary source of excess manure nutrients produced on farms with confined animals. Animal species types considered in the analysis include: feedlot beef, dairy, swine, and poultry (chicken and turkey). Numbers of confined animals and numbers of farms with confined animals—or Animal Feeding Operations (AFOs)—were obtained by county from the Census of Agriculture. This subset of animal farms does not represent the total production of manure nutrients, but rather the nutrient production for those operations for which State and Federal animal-waste disposal policies are most relevant.

Manure-nutrient production. Production of primary manure nutrients—nitrogen and phosphorus—is estimated based on census-derived animal numbers and coefficients of manure production by animal type. Computation of manure nutrients followed a three-step process. First, animal

[6] Our analysis meets all respondent confidentiality requirements of the published Census of Agriculture values.

numbers were converted to an average number of annual animal-units[7] (AU) from reported end-of-year inventory and annual sales data. Second, quantities of manure were computed using coefficients of manure production by animal type and the number of AU. Data development on manure production was geared primarily to AFOs operating above a minimum scale to reflect commercial operations.[8] Third, the recoverable portion of the manure nutrients per ton of manure was computed by animal type after adjusting for losses during collection, transfer, and storage. Recoverable manure nutrients represent that portion of manure that can be collected and applied to land net of storage and handling losses at the source site. Nutrient content of recoverable manure reflects a composite nutrient composition of manure produced by county, based on county-level distributions of animal species from the Census of Agriculture. (See Kellogg et al. (2000) for details of the estimation process for manure-nutrient production and loss coefficients.)[9]

Nutrient assimilative capacity. Farmland assimilative capacity for nutrients is estimated across farm types (i.e., non-animal farms, confined animal farms, and non-confined animal farms) based on acreage and reported yields for major field crops and pasture, aggregated to the county level. Farmland acreage available for manure spreading is calculated based on acreage in 24 major field crops and permanent pasture from the Census of Agriculture.[10] Crop and pasture land acreage in out-of-basin sink counties is assumed available for manure from the watershed, after adjusting for application of locally produced manure within the sink county. See Kellogg et al. (2000) for details of the estimation process for manure-nutrient uptake coefficients.

Manure-nutrient excess. Manure-nutrient excess refers to the quantity of manure that cannot be spread at crop-based agronomic rates on the source animal farm and thus must be hauled off the farm for land application. Manure-nutrient excess is computed under both a nitrogen-based (N) standard and a phosphorus (P) standard. These standards differ by the nutrient that determines the per-acre crop application rate, with a P standard generally allowing less manure per acre. Onfarm manure-nutrient excess is estimated by applying farm-level census measures of manure-nutrient production relative to the farm's potential to use nutrients for crop production. 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 farms with confined animals.[11] County surplus manure to be hauled off-farm is calculated for each nutrient standard based on an aggregation of farm-level manure-nutrient excess across animal farms.

Land base for surplus manure. The farmland base potentially available for surplus manure is defined to include all cropland and pasture land in 24 major crops on non-animal farms and some portion of acreage in those crops on both confined and nonconfined animal operations. Acreage in nonconfined operations was adjusted for nonrecoverable manure-N available on the farm. Acreage in confined animal operations is from farms with surplus capacity to absorb off-farm manure nutrients, accounting for their own crop nutrient needs.

[7] Annual animal-units reflect a biologically based definition of an AU of 1,000 pounds of live animal weight for feedlot beef, dairy, swine, and poultry, using average animal weights.

[8] Operations were included if: (1) animals generated more than $2,000 in sales on the farm, or (2) at least three AU were reported on the farm. Confined animals and their minimum scales were: feedlot beef (15 head), dairy (20 head), swine (50 head for slaughter), and poultry (100 head of broilers or 50 head of layers or turkeys). Of particular note, these data do not include estimates of the recoverable portion of manure from cattle, other than fattened cattle and milk cows (bulls, beef cows, dairy and beef replacement heifers, calves less than 500 pounds, and calves greater than 500 pounds not in a feedlot). If cattle other than fattened cattle and milk cows were included in the analysis, farm numbers would double, the number of AU would increase by only 6 percent, and recoverable manure nitrogen would increase by about 5 percent.

[9] Adjustments in base manure-nutrient composition measures to reflect changes in animal mix, feed mix, genetic stock, and nutrient losses may be incorporated into the model through a series of factor adjustments for nitrogen and phosphorus.

[10] Adjustments in the composite uptake rate by county to reflect changes in crop mix and/or crop yield may be incorporated into the model through a series of factor adjustments applied by farm type for crop and pasture land.

[11] We recognize this calculation process has the potential to overstate excess manure nutrients since some manure is moved off many production farms. However, total excess nutrients on confined livestock farms were more likely to be understated since neither commercial fertilizer applications nor atmospheric deposition of nutrients were considered in this analysis. Most crop farms without animals, and many farms with animals, use chemical fertilizers because they are less bulky, easier to apply, and have a more predictable nutrient content than manure.

The model assumes that all acreage on confined animal operations is available for manure spreading. In the case of non-animal farms and non-confined animal farms, a given percentage of total farmland base is assumed available for spreading, reflecting assumptions on the willingness of landowners to accept manure. Landowners may be reluctant to accept manure for various reasons. These factors include uncertainty about manure-nutrient content and availability, high transportation and handling costs relative to commercial fertilizer, soil compaction from spreading equipment, dispersion of weed seeds, concerns for added regulatory oversight, and public perception regarding odor and pathogen issues (Risse et al., 2001). While little data exist on levels of landowner willingness to accept manure on their fields, findings from this empirical study suggest that this is an important determinant of costs facing animal producers. Adjustments to reflect willingness to accept manure, specified separately for cropland and pasture land, are used to reduce the model land base effectively available for manure spreading.[12]

Manure application rates. Application rates for manure applied off-farm are computed for each within-county and out-of-county transfer based on average nutrient content of manure from the source county and average per-acre nutrient uptake on farmland in the destination county, adjusted for nutrient standard requirements and field losses. Average manure-nutrient composition by county is derived from animal mix data from the Agricultural Census and coefficients on nutrient production per AU (Kellogg et al., 2000). Average per-acre nutrient uptake rate by county is derived from cropping pattern and yield data from the Agricultural Census. Application rates and total quantity of manure that can be applied are tallied separately for confined animal farms to reflect the cropping patterns and yields specific to farms with confined animals.[13]

Manure application rates in the model vary with the nutrient standard in effect. Under an N standard, manure is applied based on crop nitrogen needs over the growing season; under a P standard, manure applications are based on crop phosphorus needs. Manure applied according to a P standard is generally applied at a lower per-acre rate than under an N standard, implying more land is needed for a given quantity of manure.[14] Reduced application rates under a P standard reflect the ratio of N and P requirements of most crops relative to the N and P ratio typical of most manure. The model user may specify the share of acres required to meet a given nutrient standard if values are known, with variable shares permitted across county subregions and crop and pasture land categories.[15]

Manure application rates are further adjusted to reflect the level of application loss. An estimated 30 percent of manure-N applied is not available to the crop due to unavoidable losses of nitrogen, primarily from volatization of ammonia. Applied manure under the N standard allows for sufficient manure-N to meet both full crop needs for nitrogen, plus the 30-percent field loss (Kellogg et al., 2000). An additional loss adjustment factor reflects the extent of manure incorporation—the base N loss factor is adjusted downward by 5 percent for fields with soil incorporation and 30 percent for fields without incorporation (Fleming et al., 1998).

[12] In order to bound potential cost estimates, the ERS study fixed levels of willingness to accept manure over a range from 10 percent to 100 percent of crop and pasture land on non-animal farms and nonconfined animal farms (Ribaudo et al., 2003).

[13] Manure application rates are automatically modified to reflect adjustments in manure nutrient content (due to changes in feed supplements or animal mix) and nutrient uptake rates (due to changes in cropping patterns or yields).

[14] Under a multi-year P standard, applied manure per acre is equivalent to that under an N standard, with treated acres rotated over a multi-year sequence to fully use excess stored manure-P, thus minimizing application costs.

[15] Since reliable data on the share of land requiring the more stringent phosphorus standard are not available at a watershed scale, separate model scenarios were specified in the ERS study as if all acres would apply manure according to either an annual N or P standard, thus bracketing the full range of possible cost effects.

Technology Use and Input Costs

Technology use and input cost data supplemented available production data from the Agricultural Census in assessing costs of production adjustments within the animal sector. Data categories involve nutrient management plans; manure storage and handling systems; commercial fertilizer offsets; industrial uses of manure; and feed supplements.

Nutrient management plans. Implementation of nutrient management plans is recommended under USDA guidelines for all confined animal operations and required under new Federal regulations for CAFOs. NRCS was the primary source of cost data for nutrient management planning (USDA, NRCS, 2003). Cost components for manure management addressed in the study include plan development, manure testing, and soil testing. Costs for plan development and manure testing are applied to the source county; soil testing costs are applied to the destination county. Plan development cost ($400/confined animal farm) was calculated as an annualized cost of developing the nutrient management elements of a CNMP based on an average of 45 hours per farm and $45/hour. Manure testing cost ($200/farm) reflects collection ($10) and analysis ($40) four times annually, applied over the number of confined animal farms in the watershed. Annual soil testing cost ($0.40/acre receiving manure) is based on $20/sample with 10 acres per soil test, or $2/acre, and one soil test every 5 years. Nutrient management plan costs not specifically related to manure land application, such as record-keeping and visual inspection, are not addressed here. Costs associated with training and certification for manure application and calibration of the manure spreader were assumed to be incorporated within reported application costs per ton of manure hauled.

Manure storage and handling systems. Manure production levels from the Agricultural Census were apportioned by manure storage and handling systems by county (table 1). Three representative manure system categories were defined in the study—lagoon systems (open, uncovered storage), slurry systems, and dry systems (primarily poultry litter in the Chesapeake Bay watershed). Allocation of manure production by storage/handling system was necessary to capture important cost differences across manure-hauling modes, hauling weight, and application.

Allocation of manure production by manure-storage system category was computed based on AUs by species as a share of total confined AUs, system shares by animal species, and manure generation per AU. Animal-units by species as a share of total confined AUs were obtained from the information developed from the Agricultural Census. Information on manure system shares for hog and dairy operations was obtained from Agricultural Resource Management Survey (ARMS) data (USDA, ERS, 2000). Manure shares for lagoon, slurry, and dry systems by animal species were based on animal operations with a single system. Hog values were based on reported values for Virginia, the sole State in the Chesapeake Bay watershed represented in the 1998 ARMS hog survey. Dairy values were reported for Virginia, New York, and Pennsylvania in the 2000 ARMS dairy survey, with estimates for Delaware and Maryland based on Pennsylvania. Beef cattle

Table 1—Manure-hauling and application costs by system type

System type	Distance interval	Hauling mode	Base charge[1]	Application cost only	Distance charge
	Miles		*$ per ton*		*$ per mile*
Lagoon	Onfarm	Pump/spray field	1.25	0.375	0.25
	0.5-2.0	Truck mounted liquid sprayer	2.00	0.600	0.30
	2.0-10.0	Truck mounted liquid sprayer	2.00	0.600	0.30
Slurry	Onfarm	Tractor/spreader (honey wagon)	2.00	0.600	0.30
	0.5-2.0	Truck mounted liquid sprayer	2.00	0.600	0.30
	2.0-10.0	Tanker truck	2.00	0.600	0.30
	>10.0	Tanker truck	2.00	0.600	0.30
Dry	Onfarm	Spreader truck	6.00	1.400	0.50
	0.5-2.0	Spreader truck	6.00	1.400	0.50
	2.0-10.0	Truck	10.00	3.700	0.11
	>10.0	Truck	10.00	3.700	0.11

[1] Includes cost of manure hauling/unloading and land application (without incorporation).

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

estimates were assumed equivalent to dairy estimates by State. Poultry production is assumed to use dry litter systems.

Manure-hauling weights are based on wet tons of manure, which contain moisture and bedding content that vary by manure system and species type (USDA, NRCS, 1999; and Barker et al., 2001). Wet manure weights are estimated from a dry manure weight (theoretic zero-moisture weight), adjusted by moisture and bedding material. Dry manure estimates per AU in dry tons per species type are: dairy, 2.156; feedlot beef, 1.143; swine, 1.2635; and poultry, 3.0 (Kellogg et al., 2000). Estimates of moisture content by system type are as follows: lagoon, 99 percent (all species); slurry, 90 percent (all species); dry, 30 percent (poultry); and dry, 50 percent (non-poultry). Manure bedding as a percentage of dry manure tonnage, by species, are: dairy, 30 percent; poultry, 10 percent; and feedlot beef and hogs, 0.[16]

Model costs for manure hauling and application are presented in table 1. Hauling and application charges were based on published literature (Pease et al., 2001; and Fleming et al., 1998), supplemented with data from NRCS (USDA, NRCS, 2003). Charges reflect a base rate per wet ton (manure loading/unloading and application) and cost per ton-mile (manure hauling). Charges are specified by storage/hauling mode and distance interval to reflect substantial differences in per-unit costs. (Application costs, expressed on a per-ton basis, are separated out for reporting purposes).

Maximum hauling distances for lagoon and slurry waste were fixed at 10 and 50 road miles, respectively; hauling distance for dry litter system waste was bounded by maximum transport distances in the model. Hauling costs were based on a round trip distance, with no backhauling. All manure-hauling costs are applied to the source county, although the model provides flexibility in assigning a share of costs across source and destination counties.

Manure incorporation costs—not reflected in application costs above—assume a cost of $6.00 per acre (Iowa State Farm Survey, 2001), with an

[16] While moisture content varies with the manure system type, manure-nutrient content per dry ton of manure is based on a composite across species by county and is not varied by manure system type.

estimated 40 percent of acres using incorporation based on information from the ARMS hog and dairy surveys.

Commercial fertilizer. The calculation of savings from fertilizer offsets assumes that organic nutrients from manure replaces chemical fertilizer on a 1:1 basis. Calculation further assumes that only the manure nutrients beneficially used in crop production are valued. Thus, excess P applied under a nitrogen standard is not considered in calculation of fertilizer savings, i.e., no benefit was given for manure nutrients in excess of crop needs. Moreover, savings do not consider the additional benefits of manure as a soil amendment (organic matter and soil tilth).

Chemical fertilizer cost savings 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/ton) for a nitrogen solution of 30 percent N, or a price per active ingredient of $0.27/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 prices for both regions—Northeast and Southeast—encompassing area within the Chesapeake Bay watershed.) Phosphorus price reflects the price per ton of triple superphosphate (45 percent P), averaged across the Northeast and Southeast ($267/ton), or an active ingredient price of $0.30/lb. P. Cost-savings for reduced fertilizer application costs (under an N standard) of $5/acre were from Fleming (1998).

Industrial uses of manure. Primary industrial uses of manure include use as an input source for power generation and as a direct ingredient in composted fertilizer products, primarily for specialty uses (i.e., residential, nursery, and golf courses). Industrial uses of manure lessen the aggregate cost of manure land application in the basin through reductions in both the amount of manure requiring application on crop and pasture land and the need for long distance hauls in areas where animal production is concentrated. Information on manure use in existing applications was obtained by processing facility via personal contact with extension agents and industry representatives.

Manure used in industrial uses is represented in the model as an exogenous reduction in the total supply of poultry litter manure to be land-applied. Manure tonnage in industrial uses, expressed in wet tons (with bedding and moisture included), is converted to dry-ton equivalents for consistency with modeling units for manure nutrients. Reductions in dry manure tonnage requiring land application are then apportioned across counties in the vicinity of a given processing facility, based on the relative proximity and volume of manure surplus by county.

Two alternative industrial use scenarios were developed for the recent ERS study, representing a near-term (2002-04) and mid-term (within 5-year) time frame (table 2). An estimated 200,000 tons of poultry litter would be diverted to industrial alternatives in the near-term, increasing to 376,000 tons within 5 years. Estimates represent approximately 0.30 and 0.65 percent of the total manure produced in the region, respectively. Near-term estimates include existing composting facilities and two new large-scale

Table 2—Estimated county-level quantities of poultry litter (wet tons) used for industrial purposes—1997, 2002-04, and 2005+

State/county	Base case (1997)	Near-term (2002-04)	Mid-term (2005+)
Delaware:			
Kent	0	0	10,000
Sussex	0	72,500	118,500
Maryland:			
Caroline	0	5,000	5,000
Dorchester	0	3,500	5,500
Somerset	0	0	28,700
Wicomico	0	45,000	61,000
Worchester	0	13,000	75,000
Virginia:			
Accomack	0	0	12,300
Rockingham	0	60,000	60,000
Total		199,000	376,000

Source: U.S. Department of Agriculture, Economic Research Service.

plants. 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. (For more information on industrial use scenarios, see Ribaudo et al., 2003.)

Feed supplements. Phytase has been used as a feed supplement for swine and poultry to increase phosphorus use in feed rations and thus reduce phosphorus content of excreted manure. The model assumes a 30-percent reduction in phosphorus content per ton of dry manure with use of phytase as a feed supplement (Council for Agricultural Science and Technology, 2002). Use of phytase is thus represented as an adjustment in the phosphorus content of the county-composite manure, based on manure-P generated by species type, the mix of AUs in the county, and the share of AUs by species receiving phytase feed supplements. The baseline model condition assumes that phytase was not used (consistent with production conditions in the 1997 Agricultural Census survey year); additional model runs were generated to reflect full phytase adoption on hog and poultry operations.

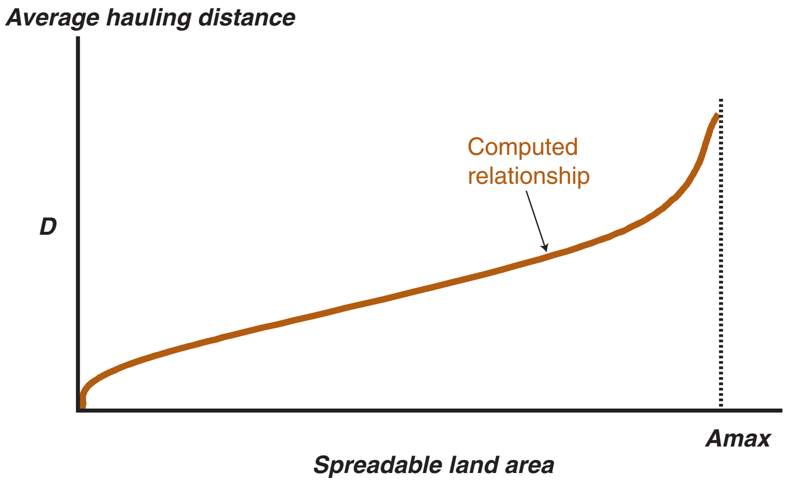
Distance Functions for Manure Hauling

Hauling distances for off-farm manure spreading are assessed based on area-to-distance functions derived from county land use patterns. These functions are a central component of the optimization model—linking the area needed for manure spreading in a destination county with average transport distance required to access the area from a given source county. By incorporating spatial relationships involving animal operations and spreadable land area, area-to-distance functions are intended to capture the inherent competition for land that exists among producers required to move surplus manure off the farm. Figure 3 shows a stylized area-to-distance relationship for manure hauling.

Competition for spreadable land is, in part, a function of the spatial pattern of spreadable area. Where farmland is scattered, a higher slope of the area-

Figure 3

Stylized area-to-distance relationship for manure hauling



Notes: *Amax* based on Census of Agriculture data. The computed relationship was based on GIS procedures applied to National Land Cover Dataset and Census of Agriculture data.

Source: U.S. Department of Agriculture, Economic Research Service.

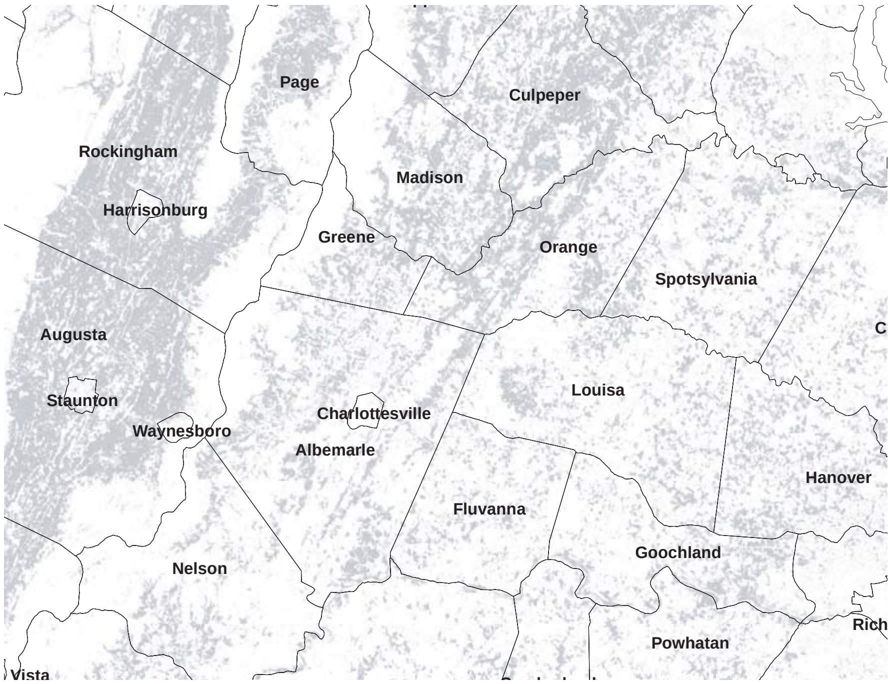
to-distance relationship reflects relatively long average hauls within the destination county to access a given acreage. Where farmland distribution is more dense, a reduced slope reflects comparatively shorter hauls to access a given acreage. The degree of competition also depends on the number, size, and proximity of confined animal operations, both within and out-of-county. Where land is limited, greater concentrations of animal production will increase competition for spreadable acreage, resulting in longer hauling distances to access available land and greater potential for out-of-county manure exports.

GIS estimation of area-to-distance functions involved a series of procedures. First, the spatial coverage for spreadable land was developed for the Chesapeake Bay watershed (CBW) study area. Second, the location of animal feeding operations was assigned within CBW basin counties. Third, area-to-distance relationships were calculated for within-county transfers. Fourth, distant intercepts and area-to-distance relationships were calculated for out-of-county transfers. Fifth, the slope of linearized area-to-distance functions were estimated for direct use in the model. Finally, area-to-distance relationships were adjusted to reflect adjustments in landowner willingness to accept manure.

Spreadable land coverage. The modeling system uses the National Land Cover Dataset (NLCD) developed by the U.S. Geological Survey (Homer et al., 2000; and USGS, 2004) to assess the spatial pattern of land available for manure application. This dataset is based on 1992 Landsat thematic mapper imagery at 30-meter resolution, classified into 21 land use categories. By combining the crop and pasture land categories, we can assemble a spatial data set of potentially spreadable land in all counties of the study region, both within the Chesapeake Bay watershed and adjacent counties within a 60-km reach of the watershed boundary. Figure 4 shows the spatial distribution of crop and pasture land in a portion of northwestern Virginia.

Figure 4

Crop and pasture land distribution in northwest Virginia



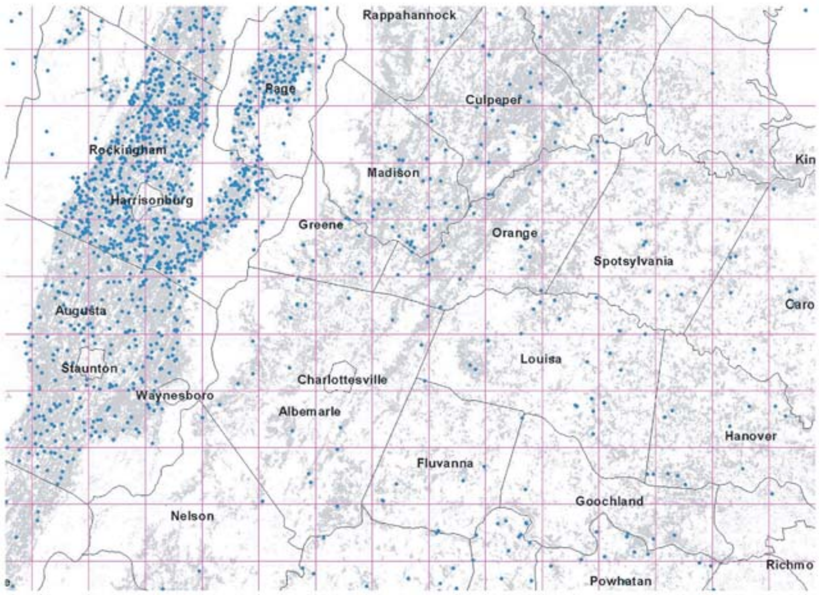
Note: Grey shading indicates crop and pasture land.

Source: U.S.Department of Agriculture, Economic Research Service, based on U.S. Geological Survey National Land Cover Dataset.

Location of animal operations. The degree of competition for spreadable land is influenced by the number, location, and size of confined animal operations. While the number and average size of animal feeding operations can be obtained from the census at a county level, the specific locations of operations within a county were unavailable. (The census does not collect precise locational information, and the data are not generally available at a regional scale from other sources.) Therefore, animal operations in the Chesapeake Bay watershed had to be locationally assigned by county within the GIS. For purposes of this analysis, animal operations were randomly assigned within crop and pasture land portions of each county, using a 30-meter grid overlay of the county. Manure production and manure by system shares are applied uniformly across animal farms by grid location in the model. Figure 5 shows the assignment of farm operations with confined animals over cropland areas in northwestern Virginia.

The random assignment of animal operations in the GIS may yield somewhat conservative estimates of actual hauling distances. While the majority of animal operations tend to be located in proximity to crop and pasture land, some operations may be separated from arable land suitable for manure spreading since production is not as sensitive to soil conditions. Moreover, the spatial concentrations of manure production within a county—reflecting the presence of larger CAFO operations and observed clustering of animal operations—will tend to increase competition for adja-

Figure 5
Assignment of animal operations



Note: 1 dot = 1 animal feeding operation. This map illustrates the spatial assignment of animal feeding operations within crop and pasture land area, by county and grid.

Source: U.S. Department of Agriculture, Economic Research Service, based on U.S. Geological Survey National Land Cover Dataset.

cent land resources. Nonetheless, the random assignment procedure was regarded as reasonable at a watershed scale, given limitations of the data.

Within-county area-to-distance relationships. We then used the GIS to compute area-to-distance relationships for within-county manure transfers for each within-basin county in the model. Area-to-distance functions for in-county manure transfers represent the average hauling distance from animal farms in a given county to spreadable land within the same county. With limited amounts of surplus manure, spreadable land is relatively accessible and hauling distances are generally short. As manure-spreading requirements increase, animal operations must compete increasingly for the same acreage—reducing accessibility and increasing the average hauling distance needed to access available acreage.[17]

Area-to-distance relationships for within-county transfers were computed for each basin county in the model by incrementally increasing, through a series of expanding 30-meter concentric bands, the search for farmland in the same source county around each of the assigned animal operations. The change in aggregate spreadable area—excluding non-farmland and farmland previously claimed by a competing operation in closer proximity—is measured for each additional distance increment. Thus, the area-to-distance relationship reflects the average distance that must be traveled across all confined animal operations to access a given level of spreadable acreage, accounting for competition among animal producers within the county. The relationship between the spreadable acreage requirement and average distance hauled is upward sloping and fairly linear along much of the observed range (computed line in figure 6).

[17] The actual area of available spreadable acreage used for manure application in a given county is determined by the optimization model, reflecting manure flows within and across counties that minimize aggregate hauling and application costs in the basin.

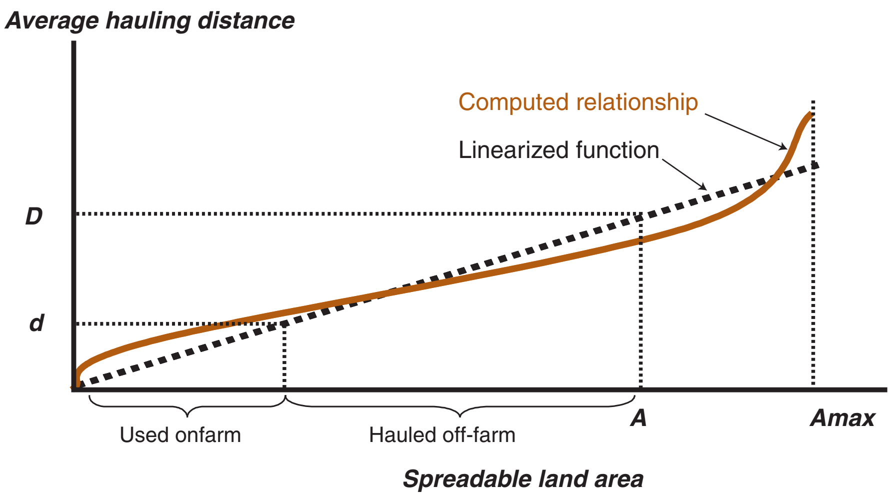
Out-of-county area-to-distance relationships. Out-of-county relationships represent manure-hauling distances from confined animal operations within a source county to spreadable acreage in other destination counties. Unique out-of-county relationships were generated for all county-to-county combinations within an assumed 60-km linear transport radius. The transport radius for the 16 counties (10 percent of all basin counties) with the highest concentrations of surplus manure relative to spreadable land was expanded to 150 km (93 linear miles), reflecting the greater hauling distances that are likely to be required from areas where animal production is concentrated.

A three-stage process was used to generate the area-to-distance relationships for out-of-county transfers (nonlinear curve shown in figure 7). First, to reduce the number of possible source-county grid alternatives, animal farms were aggregated (binned) using a 12-km grid overlay across the entire area. Although the binning procedure reduces the precision of travel distances for out-of-county functions, the procedure was necessary to ensure tractability for model optimization. Second, for each 12 km grid with animal operations, distance was measured from the grid centroid to the closest edge of spreadable area in the destination county; this distance represents the intercept term of the functional relationship. Third, the area-to-distance relationship within the destination county was computed in a fashion similar to that for in-county transfers. Thus, the area-to-distance relationship represents average hauling distance to access a given spreadable area within the destination county but measured from the direction of the source county.

Estimating linearized area-to-distance functions. For use in the regional model, area-to-distance relationships estimated from the GIS were linearized by truncating the upper and lower tails of the distribution (10 percent of acreage, respectively) and fitting a linear function to the mid-range observations (80 percent) (linear portions of figures 6 and 7). The use of linear representations reflects the significantly reduced computer memory requirements relative to non-linear functions for the area-to-distance relationship, and the fact that observed relationships are very nearly linear over

Figure 6

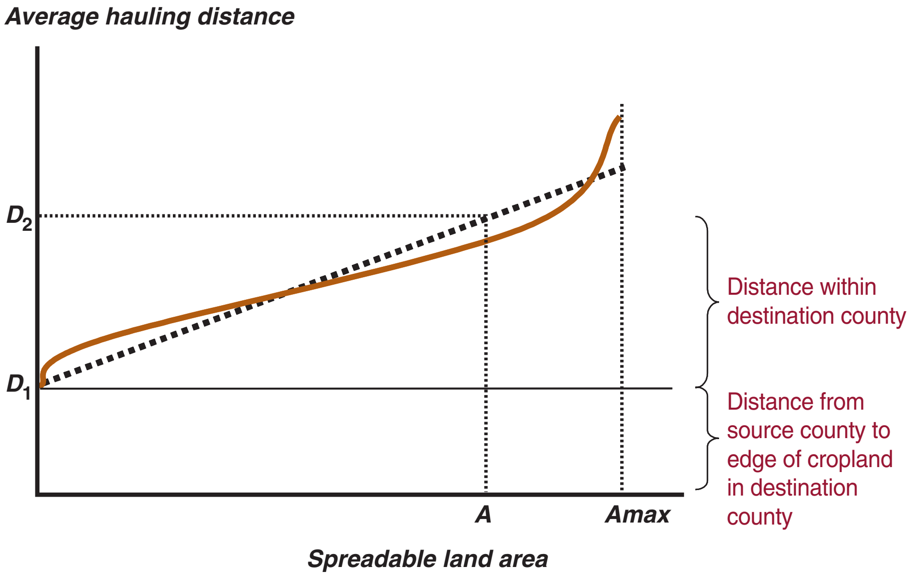
Within-county area-to-distance relationship



Source: U.S. Department of Agriculture, Economic Research Service.

Figure 7

Out-of-county area-to-distance relationship



Source: U.S. Department of Agriculture, Economic Research Service.

the relevant mid range. Regression coefficients for the linearized area-to-distance functions were incorporated as parameters in the regional model. These include a unique set of slope coefficients for each within-county and out-of-county function, as well as individual distance intercept terms by source-county grid for each out-of-county function.

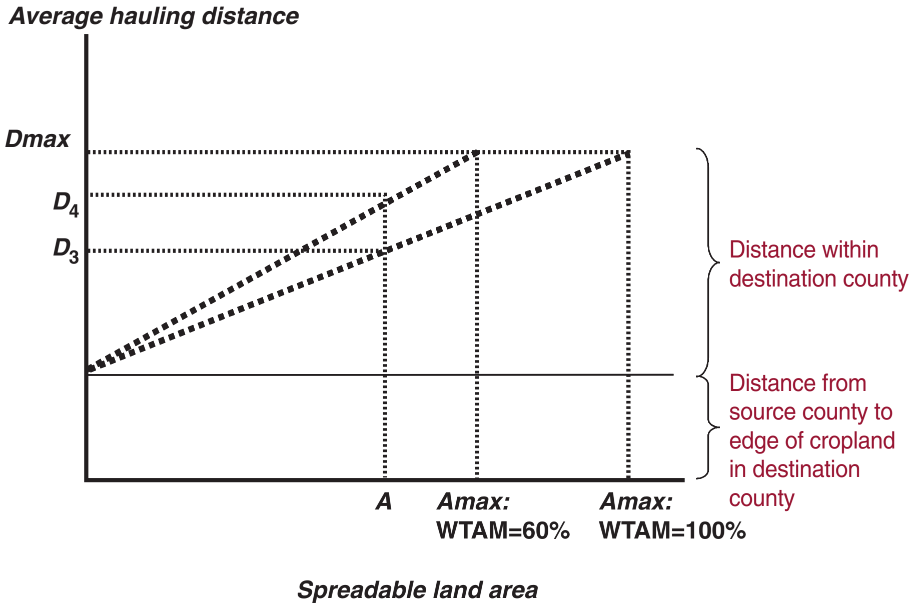
The developed slope and distance intercept terms are then applied to the spreadable acres obtained from the 1997 Census of Agriculture. The slope represents the average transport distance to use all the spreadable crop and pasture land, accounting for competition from neighboring farms that also require land to spread manure. For example, let *Amax* represent the maximum spreadable area in figure 6. If the area needed for manure land application by producers in the county for a given nutrient standard is *A*, then distance *D* would be the average distance traveled to access A acres. (In figure 6, acreage includes both on-farm acres and off-farm acres.) Figure 7 has a similar interpretation, except that a distance intercept accounts for the transport distance from the manure source to the edge of potentially spreadable land in receiving counties. Thus, the total distance to access land area A in figure 7 is represented by distance from the origin to D_2, with the origin to D_1, representing the distance to a receiving county and D_1 to D_2 the distance within the receiving county.

Adjustment for landowner willingness to accept manure. Area-to-distance functions derived from the GIS assume full acceptance of manure on all of the spreadable land base. Restrictions on availability of spreadable land due to the unwillingness of some landowners to accept manure is captured in the model through automated adjustments in both: (1) the quantity of spreadable acreage, and (2) the slope of area-to-distance functions, or hauling distance required to access a given spreadable area. Figure 8 shows the effect of a stylized reduction in available spreadable area on manure-hauling distance.

As spreadable area is reduced (to 60 percent of the maximum land base), producers must haul a greater distance on average (D_3 to D_4) to access the same amount of spreadable area A.

Figure 8

Shift in area-to-distance function with changes in landowner willingness to accept manure (WTAM)



Source: U.S. Department of Agriculture, Economic Research Service.