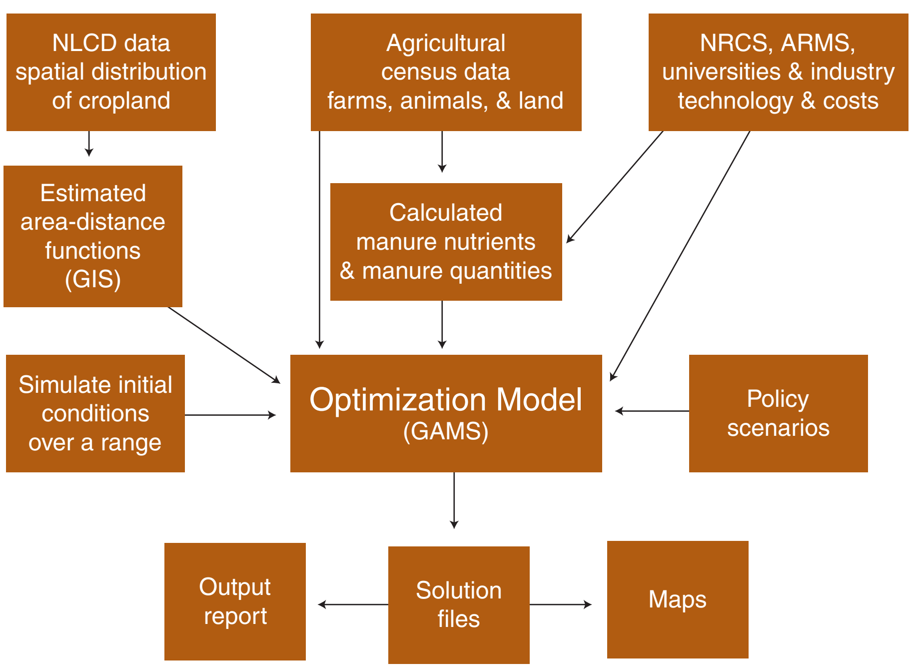
Overview of Modeling Framework

At the heart of the regional analysis conducted for the Manure Management for Improved Water Quality Project is a nonlinear mathematical programming model of animal manure-nutrient production and distribution developed for the Chesapeake Bay watershed (fig. 2). The Chesapeake Bay regional model was developed with GAMS (General Algebraic Modeling System) version 20.7, using the MINOS solver for large non-linear applications.[1] The model is designed to assess regional costs of manure management, transport, and land application in the Chesapeake Bay watershed, given the existing structure of the animal industry and manure-storage technologies currently in use. Manure production is allocated to crop and pasture land within the basin to minimize costs to the regional animal sector, subject to land availability, nutrient uptake capacity, and nutrient management policies in effect. The model is used to evaluate the cost and feasibility of land application for manure disposal, and the effect of key policy provisions and manure use assumptions on costs to the animal sector.

A defining feature of the modeling system involves the integration, within an optimization framework, of cropland coverages from the Geographic Information System (GIS) and farm-level data from the Agricultural Census, aggregated to the county level. The framework captures important spatial relationships involving animal concentrations and land available for manure spreading that can significantly affect manure land application costs faced by animal producers. Moreover, the reliance on national data series for key model parameters is itself an important element of the modeling framework, ensuring consistency of data across the watershed while facilitating the

[1] Model applications were solved successfully on a personal computer with a Pentium 4 processor and 1 GB of RAM.

Figure 2
Regional modeling system



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

potential for model updates and the potential transferability of the model to other U.S. watersheds.

Model Scope

As with any model, its strengths and limitations are reflected in the study's objectives, methodology, and analytic assumptions. The following may help to clarify the reach of the modeling framework presented here:

- The regional modeling framework provides a unique and valuable perspective on the effect of Federal regulations and guidelines for manure management, both on and off the manure-producing farm. As a large portion of manure transport costs are determined by conditions off the farm, the regional model captures important spatial interactions in animal concentrations and land available for manure spreading. The effect of spatial considerations on sector costs are not as readily addressed in farm-level or national-sector analyses.
- Reliance on national data series for key model parameters ensures consistency of data across States in the watershed. County-level specification permits important subregional differentiation in such cost determinants as animal production by species, nutrient uptake, waste technologies, and regulatory conditions across county and State boundaries. However, representative costs in the model may not accurately reflect costs faced by all animal operations in a region.
- The model assesses, in particular, the cost and feasibility of manure land application in the Chesapeake Bay watershed. While manure land application is an important element of EPA regulations and USDA nutrient management policies, the model is not designed to assess the full cost effect of a specific Federal regulation or program.
- The model focuses on those costs specific to manure hauling and land application. Cost categories not considered in the model include manure-storage infrastructure and processing. Moreover, additional capital, labor, and equipment costs not captured in the model may be needed to achieve the extent of manure land application addressed in the ERS study. A recent Natural Resources Conservation Service (NRCS) assessment suggests that these costs may be substantial (USDA, 2003).
- The model provides a static, single-year assessment of sector costs given prevailing production conditions in the latter 1990s. The model does not endogenously capture adjustments in animal concentrations, crop mix, and manure-handling systems in response to manure management policies and potential attendant changes in base estimates of manure-nutrient excess and nutrient assimilative capacity of cropland.
- Measures of manure-nutrient excess are computed from farm-level survey information, based on reported manure production and agronomic rates of land application. Applied manure in the model reflects calculated rates under a nitrogen or phosphorus standard, as actual rates and patterns of manure land application are unavailable. Thus, the model can be used to assess costs under alternative nutrient standard specifications. However, since we do not have data on actual application rates in the

1997 census base year, we cannot compare costs before and after the imposition of standards.

- As a cost-minimization model, the framework provides a partial analysis of the least-cost means of manure land disposal, based on management alternatives specified under a given scenario. The model does not assess changes in the profitability of animal production, since output prices and substitution possibilities are not considered.
- While land application of manure at agronomic rates is motivated by water policy concerns, the model is not designed to assess water quality per se. The model allocates manure across the basin, consistent with land-based nutrient standards, but does not currently track potential nutrient loadings to water bodies. An assessment of water-quality implications would require integration with other modeling tools that consider nutrient fate and transport and resulting water-quality effects.

Model Spatial Scale

The modeling analysis is defined at a watershed spatial scale. The basin encompasses approximately 64,000 square miles over portions of six States—Virginia, Maryland, Delaware, Pennsylvania, New York, and West Virginia. A watershed-wide scale was important to account for regional distribution of crop and pasture land and animal operations competing for available land resources. The watershed scale is also appropriate for future modeling extensions that would address implications of Federal manure management policies on water quality in the Chesapeake Bay. While typically run at the full watershed scale, the model may be customized to run at a smaller county-aggregate scale useful for model development and/or analysis of local issues.[2]

[2] The user specifies the set of States and/or counties to be included in a given model run.

The county serves as the primary modeling unit for the regional model. The county-level specification provides consistency with Census of Agriculture data and other data available at a county level. At the same time, the county scale permits differentiation in animal production, nutrient uptake, and waste technologies across county and State boundaries within the watershed. Subregional variation in regulatory conditions may also be incorporated, where regulations are specified at a State or county level.

The full basin model includes 160 non-municipality counties with farmland in the Chesapeake Bay watershed, each potentially representing a source and a destination county. Manure is produced in a source county and land-applied (or otherwise disposed of) in a destination county. Sink counties, or destination counties with cropland wholly outside the basin area, serve as potential receiving areas for manure exported from the watershed. The full watershed model also includes 55 sink counties that are non-municipality counties within 60 kilometers (37 miles) of cropland in the Chesapeake Bay watershed, measured from the edge of the source county's cropland base. Of the 160 basin counties in the model, 52 are edge counties containing a share of cropland acreage outside the watershed. In edge counties, manure-nutrient use is apportioned by share of cropland within the basin to more accurately account for effects at a watershed scale.[3] Appendix 1 provides a list of basin and sink counties included in the model.

[3] The share of cropland within the Chesapeake Bay watershed was calculated within the Geographic Information System, using an overlay of the watershed boundary over the U.S. Geological Survey National Land Cover Dataset.

Counties are further disaggregated according to a 12-square kilometer grid system. The sub-county grids are used to spatially assign land available for manure application within a given county (hereafter termed "spreadable" land) to match observed cropland and pasture land coverages. The sub-county grids are also used to assign location of animal operations (discussed under "Model Data: Distance Functions for Manure Hauling"). While manure flows are aggregated at the county level, transport costs are calculated based on manure quantities and hauling distance from a specific county grid point. There are 1,857 sub-county grid areas with animal farms included in the Chesapeake Bay regional model.

Model Variables and Activities

Key decision variables in the model include the quantity of manure transported by system type, the hauling distance of manure moved off the farm, and acres used for manure spreading in receiving counties. The model allocates manure across the basin to minimize the regional cost of manure hauling and land application. The direction and magnitude of manure transfers are shaped by the nutrient and moisture content of the source manure, the nutrient uptake capacity of receiving lands, and per-unit costs of manure hauling and land application. In addition, policy provisions for nutrient standards, as well as assumptions on manure use for industrial purposes and landowner willingness to accept manure on cropland, have an important bearing on regional manure allocations and sector costs. (See Appendix 2 for a listing of model variables.)

Off-farm manure transfers, including within-county and out-of-county destinations, represent the primary activities in the model. Potential county-to-county transfers were developed based on an assumed maximum radial distance of 60 kilometers (km), or 37 miles, measured from the outer edge of the source county's cropland base. For the 10 percent of modeled counties with the largest manure surplus to available land base, a maximum radial distance of 150 km (93 miles) was assumed. This combination of distances provided the model with a 150-km distance in the cases where spreadable land area is most limiting and long-distance transport might be needed, while avoiding unneeded transfer possibilities in most counties where 60 km is adequate. Even with adjustments in maximum transport distance by county to reduce transfer options, there are still 4,060 county-level transfer possibilities in the full watershed model, including within-county and out-of-county transfer combinations.

County-level manure flows represent off-farm manure transfers from all confined animal farms. Manure transfers are disaggregated by sub-county source grid, manure system type, and distance interval to more accurately assess manure-hauling costs. The full model includes over 300,000 transfer alternatives.[4] The maximum set of potential county-grid transfer alternatives generated through the automated GIS procedure was filtered to exclude county combinations with little or no probability of occurrence.[5] The filtering process slightly reduced the dimensionality of the model, which helped to reduce model convergence time.

[4] There are roughly 372,000 variables and 288,000 equations in the full model specification.

[5] Filtering criteria for manure transfers excluded: (1) source counties with zero manure surplus countywide, (2) destination sink counties with zero excess land capacity (after accounting for within-county manure surplus), and (3) county-to-county combinations involving source counties with extremely low manure surplus per cropland area within-county (<0.01 ton/ac) and more than a limited hauling distance (>5 linear km) to access out-of-county lands; source counties with very low manure surplus per cropland area (>0.01 and <0.1 ton/ac) and long hauling distances (>20 km); destinations counties with extremely high manure surplus per cropland area (>0.4 ton/ac) and very long hauling distances (>60 km); destination counties with high manure surplus per cropland area (>0.25 ton/ac) and extremely long hauling distances (>120 km), and destination counties with limited cropland area (< 15,000 acres) and extremely long hauling distances (>120 km). Source-county grid transfers were limited to those grids with AFOs. Maximum hauling distances were also applied on lagoon and slurry manure with high moisture content (10 and 50 miles, respectively), limiting potential county-to-county options for these systems.