Appendix C
Modeling Manure Management in the Chesapeake Bay Watershed

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

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

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

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

Including Air Emissions in the Modeling Framework

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

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

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

Model Data

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

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

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

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

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

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

Production Cost Data

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

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

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

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