A Regional Modeling Structure for Assessing Manure Management Policies: Application to the Chesapeake Bay Watershed

Marcel Aillery
Noel Gollehon
Marc Ribaudo
Vince Breneman

Economic Research Service,
U.S. Department of Agriculture

Abstract

A modeling framework addresses manure management policies within the Chesapeake Bay watershed. Policy focus is on manure-land application at agronomic rates, as proposed under the EPA/USDA Unified Strategy. Manure-nutrient flows are assessed subject to assimilative capacity of farmland. National data bases and GIS coverages facilitate model transferability to other watersheds.

Key Words:

manure management, confined livestock operations, regional optimization, Chesapeake Bay

Selected Paper prepared for presentation at 2001 AAEA Annual Meeting,
August 5-8, 2001, Chicago, Illinois

Marcel Aillery, Noel Gollehon, and Marc Ribaudo are agricultural economists in the Resource Economics Division, Economic Research Service, USDA. Vince Breneman is Senior GIS Analyst, Information Services Division, Economic Research Service, USDA. E-mail: maillery@ers.usda.gov, Postal address: M.Aillery, ERS-PMT, Rm.S-4037, 1800 M Street NW, Washington, D.C. 20036-5831. The views expressed are the authors' and do not necessarily represent policies or views of the U.S. Department of Agriculture.

A Regional Modeling Structure for Assessing Manure Management Policies: Application to the Chesapeake Bay Watershed

Introduction

The Chesapeake Bay is among the largest and most biologically rich estuaries in the world. The declining health of the Bay ecosystem in recent decades has prompted a major Federal/State initiative to reduce excessive nutrient loading from tributaries that drain the watershed. Excessive nutrient loads have resulted in eutrophication and related ecological shifts that adversely affect wildlife and aquatic resources (Preston and Brakebill, 1999). A number of sources contribute to the nutrient imbalance, including wastewater treatment plants, urban runoff, fertilizer applications, livestock waste production, and atmospheric deposition.

Animal agriculture is potentially a major source of nitrogen and phosphorus loadings due to concentrations of large confined animal feeding operations in some portions of the watershed. Data from the 1997 Census of Agriculture indicate that areas of the Chesapeake Bay basin, such as Maryland's Eastern Shore and the Shenandoah Valley of Virginia, produce excess manure nitrogen and phosphorus relative to the availability of nearby cropland for spreading (Kellogg et al., 2000). The concentration of large feeding operations in these areas could overwhelm the ability of a watershed to assimilate the nutrients contained in the waste, with implications for nutrient runoff and water quality.

The U.S. Department of Agriculture has established a program of research to evaluate effects of proposed regulations on the livestock industry and land and water resource quality.[1] One of several research initiatives involves development of a regional modeling framework, applied to the Chesapeake Bay watershed. The Chesapeake Bay regional manure production and transport model examines potential manure-nutrient flows and costs to the livestock sector with manure management policies proposed under the EPA/USDA Unified Strategy for animal feeding operations. Primary policy focus is on land application of recoverable manure at agronomic rates, and implications for land availability and manure hauling costs. The intent of this research is eventually to integrate the manure production/transport model with a nutrient process/water-quality model to assess potential ecological impacts of waste-management policies on the Chesapeake Bay.

In this paper, we develop the regional modeling framework for evaluating impacts on livestock operations from measures to reduce nutrient loads from animal agriculture. A brief review of the regulatory environment for animal waste management is followed by a discussion of policy issues, model data, and model structure.

A Changing Regulatory Environment

In March, 1999, the Environmental Protection Agency and U.S. Department of Agriculture issued a strategy for guiding future regulations for management of livestock waste from confined animal feeding operations (EPA/USDA Joint Unified Strategy for Animal Feeding Operations, 1999). The strategy outlined both regulatory and voluntary measures that could be taken to minimize the water quality and public health impacts from animal feeding operations. Of particular concern are proposals for stricter controls on animal waste for larger operations.

The major federal law affecting manure management on animal operations is the Clean Water Act, under which the National Pollutant Discharge Elimination System (NPDES) program covers animal feeding operations. NPDES permits are required by point sources (facilities that discharge directly to water resources through a discrete ditch or pipe) before they can discharge into navigable waters. The

---

1 Other research in this program presented at the 2001 AAEA meeting include Kaplan and Huang, Magleby, and

permits specify a level of treatment for each effluent source. Federal NPDES permits may be issued by EPA or any state authorized by EPA to implement the NPDES program.

Under 1974 EPA regulations, certain animal feeding operations (AFOs) are designated concentrated animal feeding operations (CAFOs) and considered a point source in the NPDES program. EPA's regulations (contained in 40 C.F.R. §122.23 and Part 122, Appendix B) define an AFO as a facility that meets the following criteria:

- Animals have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period, and
- Crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility.

A CAFO is defined as an AFO that:

- Confines more than 1,000 slaughter and feeder cattle, 700 mature dairy cows, 2,500 swine each weighing more than 25 kilograms, 30,000 laying hens or broilers (if a facility uses a liquid manure system), or 100,000 laying hens or broilers (if a facility uses continuous overflow watering), 55,000 turkeys, 500 horses, 10,000 sheep, 5,000 ducks, or combinations of animals totaling 1,000 animal units. The CAFO definition of animals per animal unit is specified only for slaughter and feeder cattle, mature dairy cows, swine, sheep, and horses (see 40 CFR Part 122, Appendix B).
- Confines more than 30 percent of the number of animals in the above definition and discharges pollutants into waters through a man-made ditch, flushing system, or similar man-made device, or directly into waters that pass through the facility.

Effluent guidelines promulgated in 1974 require zero discharge from the site where animals are housed,

---

Somwaru.

except in the event of a 25-year, 24-hour storm (40CFR § 412).

To fulfill part of the goals of the Unified Strategy and to mitigate the actual and potential water quality impacts posed by CAFOs, EPA is revising the regulations for CAFOs (Federal Register Vol. 66, No. 9, 1/12/01, pp. 2960-3145). One of the proposed changes is to require CAFOs to develop and implement a nutrient management plan for applying animal wastes and commercial fertilizer to cropland. The plan would be nitrogen- or phosphorus-based, depending on the phosphorus content of the soil, and would become part of the NPDES permit. This requirement will limit manure-application rates on most land, increase competition for spreadable land where such land is relatively scarce, and increase overall manure management costs. This will be especially true when nutrient plans are phosphorus-based, since smaller quantities of manure may be applied to an acre of cropland under a P-based plan relative to an N-based plan, due to the ratio of nitrogen (N) to phosphorus (P) in manure.

Policy Issues

The primary policy focus of this research is on land application of recoverable manure at agronomic rates--a central objective of the EPA/USDA Unified Strategy--and implications for producer access to spreadable acreage and manure hauling costs. Revised regulations governing manure land application will have varying sector and environmental impacts, depending on a number of factors to be examined in this research. In addition, an assessment of land application impacts provides a baseline reference for analysis of alternative animal-waste disposal measures such as composting, livestock feed, incineration, and bioenergy production.

Changes in nutrient standards for manure application, and the implementation of standards across the watershed, will have an important bearing on manure applied and hauling requirements. The availability of crop and pastureland for manure spreading is a critical issue, given the competition for land that revised regulations are likely to generate. The willingness of property owners to accept manure on eligible acres is an important consideration, yet this variable remains largely unknown. Spatial and temporal adjustments in soil phosphorus concentrations may affect both the availability of spreadable acreage and the recommended nutrient standard. Stream buffer requirements may reduce both the area of spreadable acreage as well as runoff coefficients for applied manure-nutrients. Farmland conversion rates may also need to be considered in a long-term analysis of manure policy impacts on the Chesapeake Bay watershed.

Assimilitive capacity of manure-nutrients is further affected by nutrient uptake rates per unit-land and manure nutrient content. Nutrient uptake rates may vary over time due to cropping pattern shifts and yield adjustments. Nutrient content of manure may also adjust with changes in genetic stock of animals, animal-unit mix, or animal feed mix. All of these issues affect the capacity for animal-waste disposal through land application in the watershed.

The Regional Model

A regional modeling framework for evaluating livestock-waste management policies in the Chesapeake Bay watershed (figure 1) is under development. The regional modeling framework offers several attractive features:

- The region specification captures the critical dimension of competition for land facing livestock operations required to land-apply manure—which farm-level models cannot as readily address.

- County and local data are used to capture heterogeneity in technologies and land-quality conditions across the region, though it may not replicate area-specific conditions of a farm-level model.
- The model may also be used to address manure management policies specific to a State or substate area.
- Output from the regional production/transport model, indicating production and flows of manure nutrients across the region, can be integrated with water-quality models, such as the USGS-SPARROW model calibrated for the Chesapeake Bay and tributary streams, to evaluate water-quality impacts at a watershed scale.
- The regional model can be readily updated as county-specific Census data and GIS coverage data become available.
- Use of county Census data and GIS coverages available at the national scale facilitates transferability of the modeling framework to other regions of the U.S.

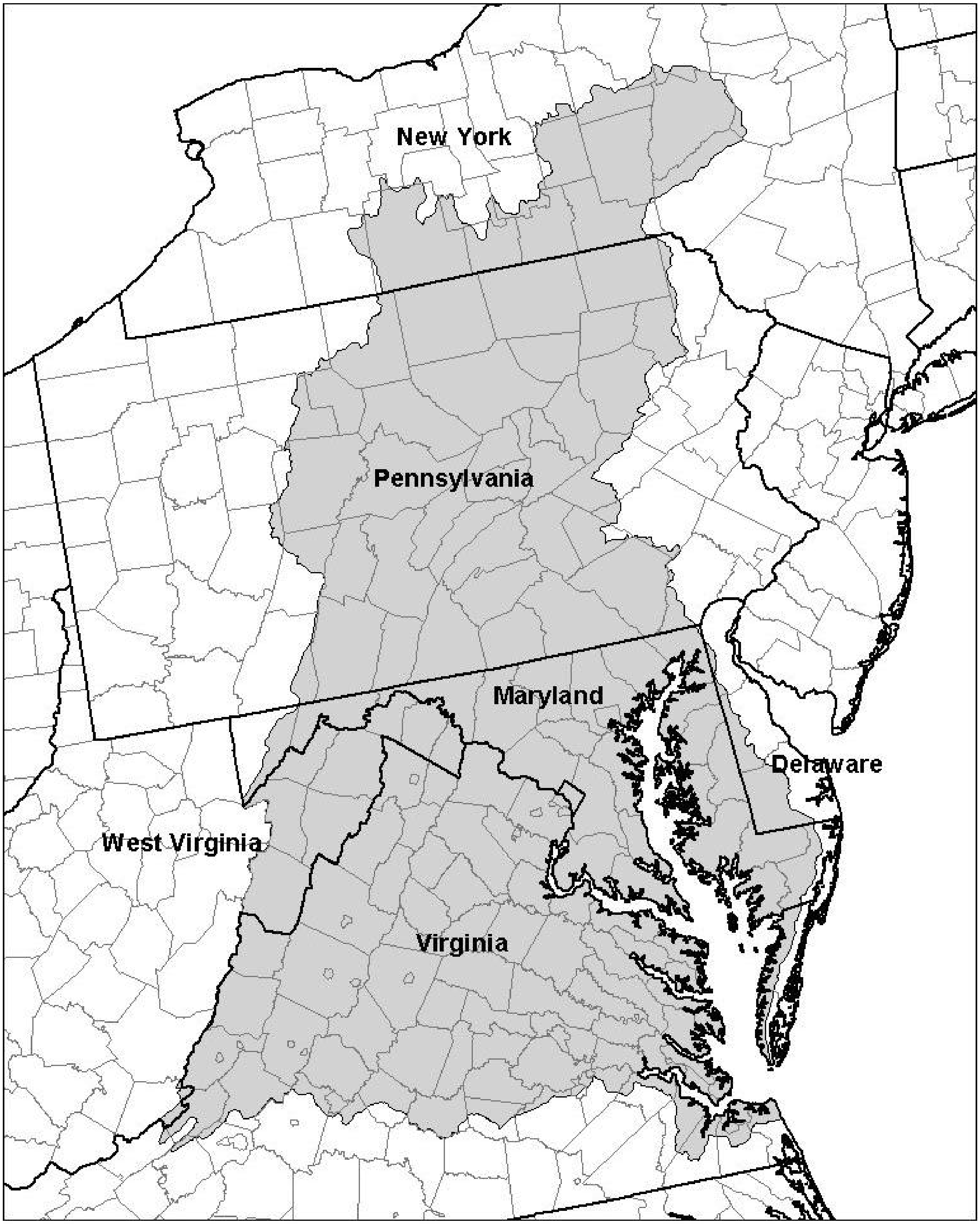


Figure 1. The Chesapeake Bay Watershed

Model Data

Two primary data sources form the basis of the model data set: the 1997 Census of Agriculture and the National Land Cover Dataset from USGS. Farm-level Census data were used to generate county-level measures of livestock operations and animal-units, total manure production, excess recoverable manure, manure-nutrient content, and potential assimilative capacity of the land for applied manure nutrients. The National Land Cover Dataset was used to account for the spatial pattern of land available for manure spreading and to simulate the spatial distribution of livestock operations. The data sets are discussed here.

Agricultural Census. Our analysis uses on-farm balance of 1) manure nutrient production relative to 2) the farm's potential to utilize nutrients for crop production, based on farm-level data collected for the 1997 Census of Agriculture. Results based on the farm-level information are then summed across animal types and aggregated at the county level.[2] Using farm-level data, we can estimate cropland acres, crop production levels, and potential manure nutrient use for crop production specific to confined-animal producers.

---

[2] Our analysis meets all respondent confidentiality assurances that are required to publish Census of Agriculture values.

This study focuses on manure management in the context of current State and Federal policy. Therefore, data development was geared primarily to farms with confined animal types operating above a minimum scale to reflect commercial operations.[3] This subset of farms does not represent the total production of manure nutrients, but rather the nutrient production for those operations for which animal-waste disposal policies will most likely be relevant (see Kellogg, et al. (2000) for estimates of all manure production).

Computation of manure nutrients followed a three-step process. First, animal numbers were converted to an average annual animal-unit (AU) inventory from reported end-of-year inventory and annual sales data. We applied 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. Second, quantities of manure were computed by applying coefficients of manure production by animal type based on the number of AU. Third, we computed the recoverable portion of the manure nutrients per ton of manure 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 losses. See Kellogg et al. (2000) for details of the estimation process and manure/nutrient production coefficients.

Potential manure nutrient use by the farms on which manure nutrients were produced was also estimated. Land area and per-acre nutrient uptake for the production of 24 major field crops and permanent pasture was computed for each farm in the Census based on reported yields and acres. Manure nutrient production on confined livestock farms was assessed against crop and pasture

---

3 Operations were included if animals generated more than $2,000 in sales or at least 3 AU were 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 turkeys). 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

assimilative capacity on those same farms to compute a farm-level "excess" of manure nutrients. The potential assimilative capacity of farms without confined animals was also computed using the same procedures in order to measure the potential use of manure on near-by lands. We recognize this calculation process has the potential to overstate excess manure nutrients as 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 livestock, and many farms with livestock, use chemical fertilizers as they are less bulky, easier to apply, and have a more predictable nutrient content than manure.

National Land Cover Dataset. To assess availability and spatial pattern of spreadable land for manure application, the analysis uses the National Land Cover Dataset developed by the US Geological Survey. The dataset is based on 1992 Landsat thematic mapper imagery at 30m resolution, classified into 21 landuse categories. By combining the crop and pasture categories we were able to assemble a maximum spreadable land base for all counties in the study region. Figure 2. visually depicts a small section of this dataset in northwestern Virginia.

---

and milk cows, were included in the analysis farm numbers would double, the number of AU would increase by only six percent, and recoverable manure nitrogen would increase by about five percent.

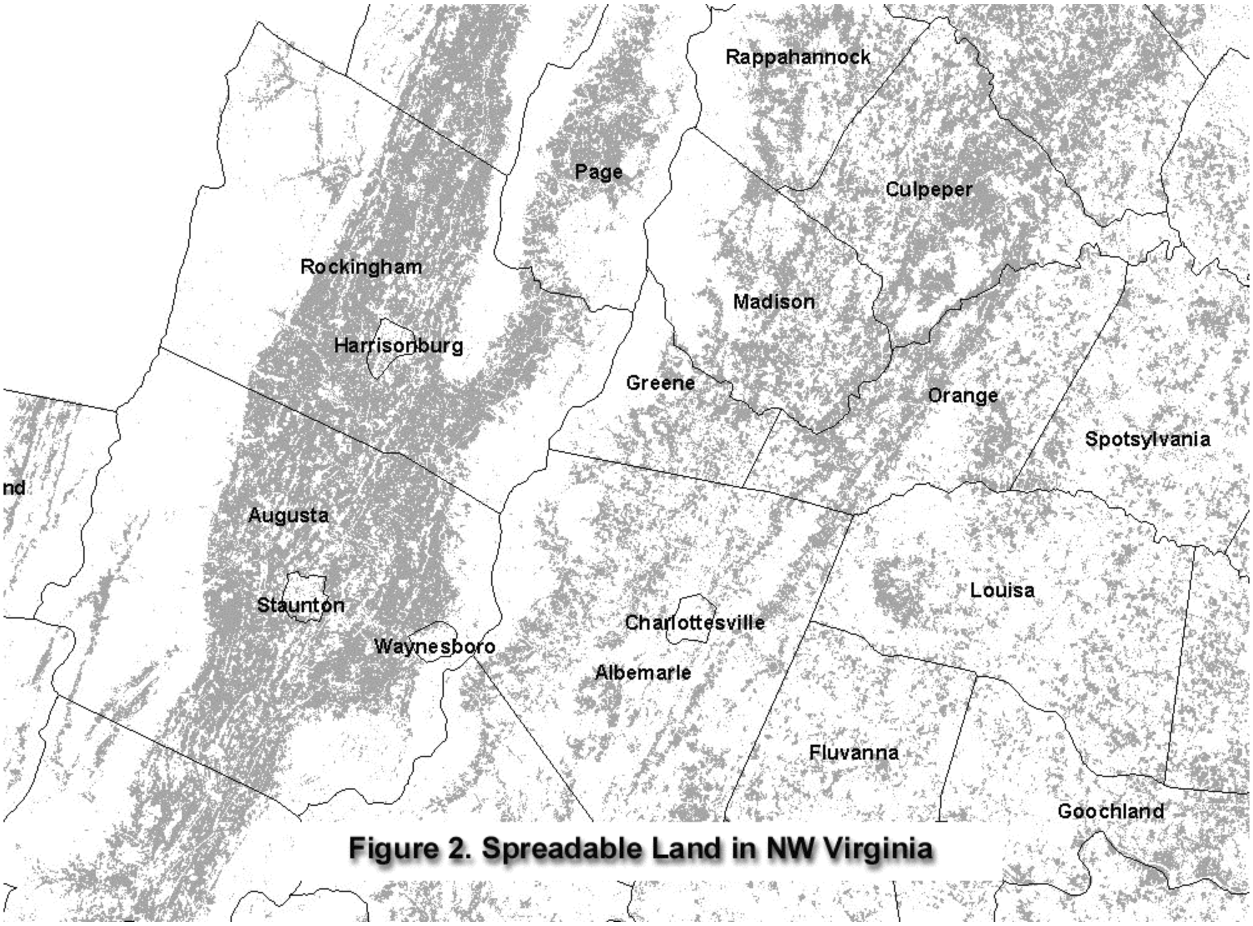


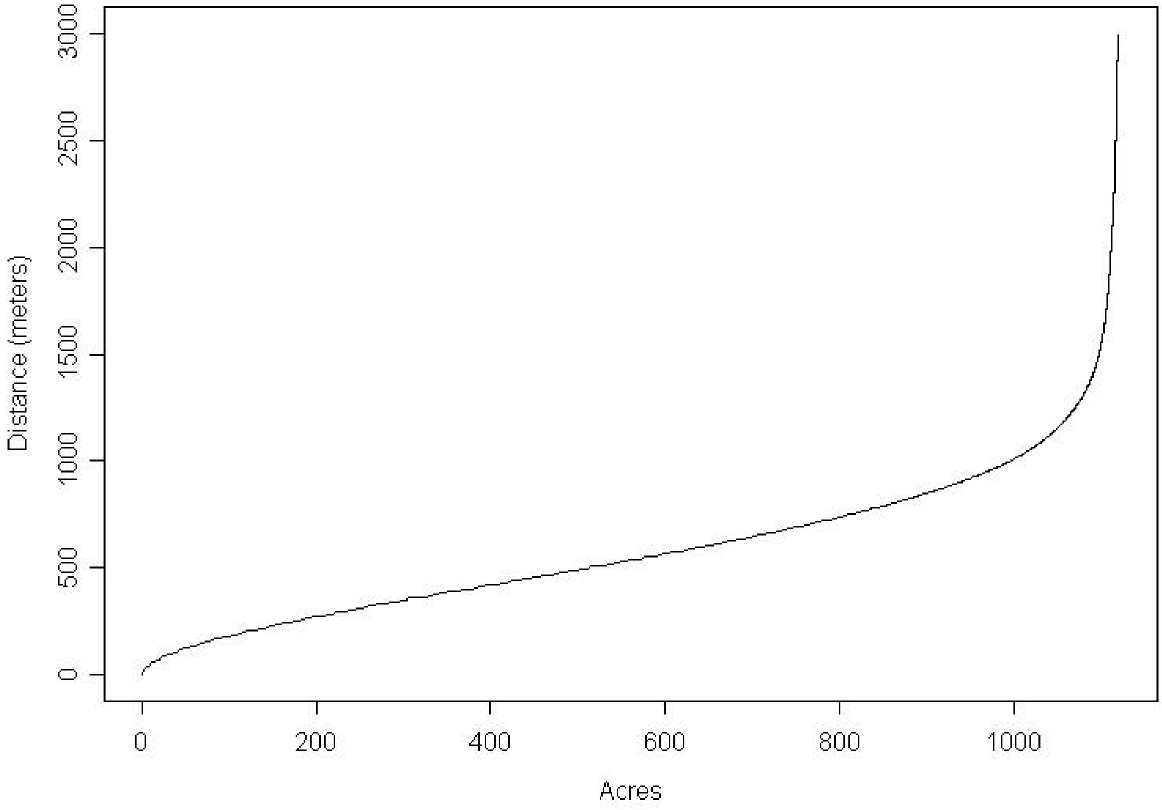
Figure 2. Spreadable Land in NW Virginia

GIS Data. To estimate hauling distance requirements for manure spreading manure, a Geographic Information System (GIS) is used to create area-to-distance functions for each county and farm in the study region. These functions are a central component of the optimization model, linking the area needed for manure spreading with the distance farmers would be required to travel to dispose of excess manure.

Area-to-distance functions are specified separately for within-county and out-of-county transfers. Within-county distance functions are generated by calculating the distance from all farms within a given county to spreadable land in that county. With limited amounts of excess manure, spreadable land is relatively accessible and hauling distances are generally short. As manure spreading requirements increase, farms must compete increasingly for the same acreage--reducing accessibility and increasing the distance needed to access available acreage.[4] As Figure 3 suggests, the relationship between the spreadable acreage requirement and average distance hauled is upward sloping and fairly linear along much of the observed range. The slope of the function varies somewhat across counties, based on factors discussed below.

The out-of-county distance functions were generated somewhat differently than within-county functions. Out-of-county functions represent hauling distances for livestock operations in a source county to spreadable acreage in adjacent counties. Each inter-county function is unique; reflecting estimated distance from the source-county livestock farm and the spatial pattern of spreadable land in the destination county, as encountered from the direction of the source county. A two-stage process was used to generate the average distance functions. First, the distance from each farm in a source county to the edge of spreadable acreage in a destination county was calculated; this distance represents the intercept term for the area-to-distance functions. Second,

Figure 3. Area-to-Distance Function



the relationship between spreadable acreage to average hauling distance, or slope of distance function, was generated for the destination county by calculating hauling distance required for a given area of spreadable acreage, measured from the direction of the source county. Thus, out-of-county hauling functions are the combination of source-to-destination county intercept and slope of the area-to-distance relationship for destination counties.

The within-county and out-of-county distance functions are affected by three primary factors: 1) the spatial pattern of spreadable land; 2) the number of farms competing for spreadable land; and 3)

---

4 The actual area of available spreadable acreage used for manure application in a given county is determined by the

the location of farms relative to spreadable land. The pattern of spreadable land is important when generating the area-to-distance functions in that it affects land accessibility. Where spreadable land is scattered throughout a county, average farmer access to spreadable land will be low relative to a county where cropland and pastureland are clustered. In figure 2, showing spatial distribution of crop and pasture lands in northwestern Virginia, Culpeper County has a more scattered pattern of spreadable land than Rockingham County. Therefore, Culpeper county farmers would need to travel further on average than Rockingham county farmers to access the same amount of spreadable land (ignoring, for the moment, the issue of competition for land). In graphical terms (figure 3), the slope of the area-to-distance function would be higher for Culpeper county, since hauling distances are greater for a given area of spreadable land. The effect of the spatial pattern of spreadable land is most apparent in assessing out-of-county distance functions. As figure 2 would suggest, producers in Augusta county have greater access to spreadable land in Rockingham county (i.e., reduced function slopes) than producers in Green county, located at some distance away, even though both counties are adjacent to Rockingham county.

The number of confined livestock farms in a county—obtained from the Agricultural Census—is also an important determinant in the calculation of area-to-distance functions. As the number of farms in a county increases, average travel distance within-county decreases up to the point where competition occurs. However, an increase in the number of farms reduces the average distance at which farms compete. As competion increases due to the number of farms, average hauling distance increases and out-of-county exports become more viable. In figure 2, the minimizing effect of cropland clustering on hauling distance in Rockingham county is offset by the high concentration of confined livestock

---

optimization model, reflecting manure flows within and across counties that minimize disposal costs.

operations in the area. With increased competition for land from in-county and out-of-county operations, producers are required to haul greater distances (i.e., moving further along the area-to-distance function) to dispose of a given quantity of excess manure.

While the number of confined livestock operations is available from the Agricultural Census, we do not know the specific locations of farms. Using the GIS, livestock operations were assigned randomly across the crop and pastureland portions of each county. We feel that this is a reasonable assumption. Although livestock operations may be removed from arable land since animal production is not as sensitive to soil conditions, the majority of animal feeding operations tend to be located in proximity to crop and pasture land. The random farm location assumption probably yields somewhat conservative estimates of distance to spreadable land and related hauling costs, due to observed clustering of animal operations and resultant competition for land resources.

To integrate the GIS data into a format useable for the optimization model, regression coefficients for the area-to-distance functions were generated for within-county and out-of-county transfers. A single set of coefficients was produced for each within-county function, by county. For out-of county functions, separate sets of coefficients were generated for each source farm and destination- county combination within a 60-km radius. To reduce the number of manure source and destination combinations, livestock farms were aggregated (binned) by 6-km grid across the watershed area. Although the binning procedure reduces the precision of the intercepts for out-of county functions, this was necessary for tractability of the optimization problem. In addition, estimated functions generated from the GIS were linearized for modeling purposes, by truncating the upper and lower tails of the distribution (10 percent of acreage) and fitting a linear function to the mid-range observations (80 percent). The use of linear representations reflects the high computer memory requirements for non-linear distance functions, and the fact that observed functions were very nearly linear over the relevant mid-range.

Regional model structure

The focus of the initial model development activity has been two-fold: 1) to construct an accounting structure that tracks manure and related nutrient flows within the basin, from manure source to site application/disposal, and 2) to provide a framework for evaluating policy mechanisms that may be brought to bear on a regional scale to meet objectives of the EPA regulations.

The county is the effective modeling unit for the regional model. The county-level specification provides consistency with Census data and other county-level data, while permitting differentiation of institutions and regulatory conditions across county and State political boundaries within the watershed.

A county may be both a ‘source’ county and a ‘destination’ county, for purposes of tracking manure and nutrient flows. Manure is produced in a source county and used (or otherwise disposed of) in a destination county. ‘Model’ counties include all non-municipality counties within the watershed with farmland. The full watershed model includes 160 model counties, representing potential ‘source’ and ‘destination’ counties. ‘Sink’ counties refer to ‘destination’ counties outside the modeled area that serve as a potential sink for manure from ‘model’ counties, subject to net assimilative capacity after accounting for in-county manure applications. There are 104 sink counties included in the full watershed model, comprising non-municipality counties within 60 kilometers (37 miles) of a ‘model’ county (measured from the edge of the source model-county cropland base). ‘Edge’ counties, or those that straddle the watershed boundary, are effectively treated as two separate modeling units to account accurately for manure flows within and outside the basin.[5]

The optimization model is designed to minimize the cost of excess manure disposal, subject to land availability for manure applications and other disposal options. The model allocates manure flows across the watershed that minimizes the objective function expression:

Minimize cost =

$$(1) \quad \sum_{ct} \sum_{ct2} [HC_{ct,ct2} + ST_{ct} + AP_{ct2} + NM_{ct2} + MC_{ct2} + LV_{ct} - FC_{ct2} - MR_{ct2}]$$

Disposal costs for excess manure, broadly defined here, encompass a range of costs incurred across source (ct) and destination (ct2) counties. These include manure hauling cost (HC), manure storage cost (ST), land application cost (AP), nutrient management plan charges (NM), cost of purchased manure (MC), and potential reductions in animal-units to comply with manure regulations (LV). Aggregate costs may be adjusted to reflect cost savings due to chemical fertilizer reductions (FC) and revenues from sale of manure (MR). The objective function is readily customized to reflect various combinations of cost components.

'Manure transfers' represent the primary activities in the model. Transfers refer to movement of manure (and nutrients) from source to destination counties, and include both within-county transfers and out-of-county exports. Potential transfer county combinations were developed based on a maximum

---

5/ The model has been set up to offer maximum flexibility in defining the modeling area. The user specifies model and sink counties to be included in a given run, and matrix dimensions are automatically redefined. This is particularly helpful in model development when working with a smaller model is desirable. This is also useful when a given analysis focuses on a subset of counties, as in the case of a regulation applying to poultry production on the Eastern Shore.

average hauling distance of 60 kms (37 miles), measured from edge of source cropland base.[6] There are roughly 4,150 county-level transfer possibilities in the full watershed model, including within-county and out-of-county transfer combinations; out-of-county transfers are further disaggregated by substate grid.

The primary decision variables in the model represent 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 livestock farms (manure sources), and manure-nutrient use; and 3) various cost accounting equations.

The concept of assimilative capacity, or the capacity of the land to utilize land-applied manure-nutrients, is a major determinant of manure flows in the model. Factors affecting assimilitative capacity include: 1) the extent of spreadable acres, 2) nutrient uptake rate of receiving fields, 3) nutrient content of manure, and 4) nutrient standard applied. In general, manure quantities are the basis of model costs, while manure nutrients determine the volume and direction of manure flows.

Primary manure transfer equations are as follows:

$$(2) \quad \text{M\_TRAN}_{ct,ct2} = \text{M\_APPL}_{ct,ct2} * \text{AC\_SPR}_{ct,ct2}$$

$$(3) \quad \sum_{ct} \text{AC\_SPR}_{ct,ct2} \leq \text{AC}_{ct2}$$

$$(4) \quad \text{M\_TRAN}_{ct,ct2} = \sum_{gr} \sum_{sy} \sum_{ds} \text{M\_TRN}_{ct,gr,ct2,sy,ds}$$

$$(5) \quad \text{M\_TRN}_{ct,gr,ct2} \leq \text{M\_PRD}_{\text{ct,ct2}} * \text{SHR}_{\text{ct,gr,ct2}}$$

---

[6] The actual distance for individual hauls may exceed the weighted-average distance threshold for a given out-of-county transfer. The maximum average hauling threshold of 60 kms could be relaxed, but at a cost of model dimensionality.

where *gr* is county grid location, *sy* is manure system (lagoon, slurry, dry), and *ds* is distance interval in kilometers (<.5, .5-2, 2-10, >10).

In Equation (2), manure by county transfer (M_TRAN) is defined as the product of manure application rate (M_APPL) and receiving acres (AC_SPR) in the destination county. Manure application rate was estimated for each individual county transfer based on average nutrient content of manure from the source county; average uptake rates for N and P in the destination county, weighted across cropland and pasture for each of three farm types; and the nutrient standard in effect (i.e., extent to which phosphorus application may exceed agronomic rates). Data specification by farm type--non-livestock farms, non-confined livestock farms, and confined livestock farms--was important in order to capture potential variation in uptake rate due to cropping/pasture mix and yield.

The model provides flexibility in modifying manure application rates to reflect a given policy scenario. Acreage shares by nutrient standard (and permissible levels of ‘over-application’ of manure-P) may be specified to reflect differences in background concentrations of soil phosphorus, differing regulations across State lines, and regulatory changes over time. Nutrient uptake rates may be adjusted to reflect changes in base cropping patterns and yields for alternative farm categories within the watershed. The model can also be used to examine potential changes in nutrient content of manure due to changes in genetic stock of animals, animal-unit mix, or animal feed mix.

Equation (3) restricts applied manure from all potential source counties to total spreadable acreage (AC) in the destination county. Total spreadable acreage includes: all acreage in non-livestock farms, some portion of acreage in non-confined livestock farms, and some portion of acreage in confined livestock farms. Acreage on non-confined livestock farms assumed available for manure spreading is calculated based on 1) the share of non-recoverable N from non-confined farms considered available, to 2) total N uptake on these farms.   Available acreage on confined livestock farms reflects total N and P surplus not used in farm-level excess calculations (from the Census data), and weighted manure applications per acre.

The model provides flexibility in modifying assumptions on acreage availability for manure spreading. Assumptions on the willingness of landowners to accept manure can be captured through automated adjustments to the slope of area-to-distance functions. Acreage shares for 'willingness to accept' may be specified separately for cropland and pastureland. Other acreage adjustments that may be examined involve crop-acreage shares not likely to use manure (i.e., vegetables or soybeans), variation in phosphorus concentration of soils, stream buffer requirements, and farmland conversion rates.

Equation (4) sets county-level transfers (M_TRAN) equal to the sum of manure transfers by system type *sy* and distance interval *ds*. Equation (5) bounds manure transfers by the share (SHR) of total county-level manure production (M_PRD) across source-county grids *gr*, based on allocation procedures used in the GIS system.

Hauling distances are computed based on Equations (6) – (8).

$$(6) \qquad DS_{ct,gr,ct2} = [\boldsymbol{a}_{ct,gr,ct2} + (\boldsymbol{b}_{ct,ct2} * AC\_SPR_{ct,ct2})] * ADJ_{ct,ct2}$$

$$(7) \qquad DS_{ct,gr,ct2} * M\_TRN_{ct,gr,ct2} = \sum_{sy} \sum_{ds} (DST_{ct,gr,ct2,sy,ds} * M\_TRN_{ct,gr,ct2,sy,ds})$$

$$(8) \qquad D\_MN_{ds} \leq DST_{ct,gr,ct2,sy,ds} \leq D\_MX_{ds}$$

In Equation (6), average hauling distance (DS) from source county *ct* and grid *gr* is calculated as a function of spreadable acres in the destination county *ct2*, based on ***a*** and ***b*** coefficients from the GIS-derived econometric functions. A ‘road density’ parameter (ADJ) is used to convert linear distance to road miles. In Equation (7), average hauling distance represents a weighted-average of hauling distances by manure-waste system type *sy* and distance interval *ds*. Minimum (D_MN) and maximum (D_MX) distance is specified by distance interval in Equation (8).

Stocks and flows of manure nutrients *np*—nitrogen or phosphorus—are tied to manure quantities as follows:

$$(9) \qquad \text{NP\_PRD}_{ct,ct2,np} = \text{M\_PRD}_{ct,ct2} * \text{NP\_M}_{ct,np}$$

$$(10) \qquad \text{NP\_TRN}_{ct,ct2,np} = \text{M\_TRN}_{ct,ct2} * \text{NP\_M}_{ct,np}$$

$$(11) \qquad \text{NP\_EXC}_{ct,ct2,np} \leq \text{M\_EXC}_{ct,ct2} * \text{NP\_M}_{ct,np}$$

Manure nutrients are computed for total manure produced (Equation 9) and total manure transferred (Equation 10), based on county-average nutrient content per dry ton of manure (NP_M) from the Census data. Total excess nutrients N and P were obtained from farm-level Census data on manure production and onfarm assimilitative capacity, aggregated to the county level. Excess manure (manure subject to off-farm disposal) is calculated in Equation (11) based on the higher of excess N or excess P. In most cases, excess manure is derived from excess P, as phosphorus is generally the ‘limiting nutrient’ from a manure application perspective.

Manure hauling cost, the primary cost component in the model, is computed based on base rate per ton hauled (C1), hauling cost per ton-mile (C2), actual distance hauled (DST), quantity of manure hauled in dry tons (M_TRN), and manure moisture content (MS).

$$(12) \quad \text{HC}_{\text{ct,ct2}} = \sum_{gr} \sum_{sy} \sum_{ds} \left[\text{C1}_{sy,ds} + (\text{C2}_{sy,ds} * \text{DST}_{ct,gr,ct2,sy,ds}) \right] * \left(\text{M\_TRN}_{ct,gr,ct2,sy,ds} / (1 - \text{MS}_{sy}) \right]$$

Hauling costs vary substantially across animal waste systems--lagoon, slurry, and dry--reflecting differences in manure moisture content and equipment complement by system. The model simulates a stepwise cost function for manure hauling cost, with cost coefficients defined by waste-system type and distance interval hauled. Public cost-share rates and cap amounts for manure hauling may be specified, as well as assignment of hauling costs across source and destination counties since costs may be borne by either the producer (operator/integrator) or user (land applier/processor). While these factors reflect a redistribution of costs rather than a true cost reduction, the distribution of costs can have significant implications for the regional livestock sector.

Summary

Management of livestock waste is an important issue in the Chesapeake Bay watershed, given the concentration of livestock production in areas of the basin and the major State and Federal commitment to protection of Bay resources. Proposed regulations on the handling of animal waste are likely to have a significant impact on the livestock sector. This is particularly true in the Chesapeake watershed, where counties with concentrations of excess manure nutrients rank among the highest in the nation.

The regional modeling framework, combining farm-level Census data with GIS spatial data coverages, provides a framework for evaluating potential livestock sector impacts from regulations governing animal-waste disposal. Of particular importance is the issue of assimilitative capacity of manure nutrients—a subject of ongoing research—and the heightened competition for land that is likely to occur with land application of manure under proposed nutrient standards. Ultimately, the integration of the region livestock waste model with nutrient process models should help us to understand the effect of manure disposal policies on water-quality indicators and other measures of ecosystem health at a watershed scale.

References

EPA/USDA Unified National Strategy for Animal Feeding Operations, March 1999.

Huang, Wen-yuan, Richard Magleby, and Agapi Somwaru. The Economic Impacts of Alternative Manure Management Regulations in the Heartland: An Individual-Farm Analysis. USDA-ERS, paper prepared for presentation at the 2001 AAEA Annual Meeting, August 5-8, 2001, Chicago, Illinois.

Kaplan, Jonathan D. Prevention versus Utilization of Excess Nutrients from Animal Feeding Operations: The Case of Managing Nutrient Uncertainty. USDA-ERS, paper prepared for presentation at the 2001 AAEA Annual Meeting, August 5-8, 2001, Chicago, Illinois.

Kellogg, Robert, Charles Lander, David Moffitt and Noel Gollehon. Manure Nutrients Relative to the Capacity of Cropland and Pastureland to Assimilate Nutrients: Spatial and Temporal Trend for the United States. USDA-NRCS, October 2000.

Preston, S.D. and J.W. Brakebill. Application of Spatially Referenced Regression Modeling for the Evaluation of total Nitrogen Loading in the Chesapeake Bay Watershed. Water-Resources Investigations Report 99-4054, U.S. Geological Survey. 1999.