A Carrot-and-Stick Approach to Environmental Improvement: Marrying Agri-Environmental Payments and Water Quality Regulations

Robert C. Johansson and Jonathan D. Kaplan

Agri-environmental programs, such as the Environmental Quality Incentives Program, provide payments to livestock and crop producers to generate broadly defined environmental benefits and to help them comply with federal water quality regulations, such as those that require manure nutrients generated on large animal feeding operations to be spread on cropland at no greater than agronomic rates. We couch these policy options in terms of agri-environmental "carrots" and regulatory "sticks," respectively. The U.S. agricultural sector is likely to respond to these policies in a variety of ways. Simulation analysis suggests that meeting nutrient standards would result in decreased levels of animal production, increased prices for livestock and poultry products, increased levels of crop production, and water quality improvements. However, estimated impacts are not homogeneous across regions. In regions with relatively less cropland per ton of manure produced, the impacts of these policies are more pronounced.

Key Words: agricultural sector simulation, agri-environmental programs, manure nutrients, water quality

The U.S. Environmental Protection Agency (EPA) estimates that agricultural pollution contributes to 60% of impaired streams, 30% of impaired lakes, 15% of the impaired estuaries, and 15% of the impaired coastal shoreline assessed (U.S. EPA, 2002a). All told, more than 11.6 million acres of U.S. rivers and lakes are considered impaired by excessive discharge of agricultural pollutants: soil, pesticides, pathogens, nitrogen, and phosphorus (U.S. EPA, 2002b). U.S. policy makers have adopted carrot-and-stick approaches to address some of the water quality problems linked to agricultural production and subsequent pollution. Federal funding targeted toward the mitigation of agricultural impacts on water quality has increased ("carrots"), and more stringent water quality regulations have been enacted pertaining to agricultural production ("sticks").

Specifically, funding for conservation practices on animal feeding operations (AFOs) and cropland through the Environmental Quality Incentives Program (EQIP) has been authorized to increase from 2002 levels of $200 million to more than $1 billion by 2005 [U.S. Department of Agriculture/ Natural Resources Conservation Service (USDA/ NRCS), 2002]. EQIP provides agri-environmental payments to producers in order to generate broadly defined environmental benefits and to assist producers in complying with local, state, and federal water quality regulations. In addition, EPA has mandated nutrient standards for the largest AFOs, known as concentrated animal feeding operations (CAFOs). These standards essentially require manure nutrients generated on CAFOs to be spread on

Robert C. Johansson is an economist with the Resource and Environmental Policy Branch, Economic Research Service, U.S. Department of Agriculture, Washington, DC; Jonathan D. Kaplan is assistant professor, Department of Economics, California State University, Sacramento. The authors thank Marcel Aillery, Marc Ribaudo, and two anonymous reviewers for their helpful comments on earlier drafts of this paper.

This paper was presented at a workshop sponsored by: USDA-NRI, USDA-ERS, and NERCRD. The views expressed herein are those of the authors and not necessarily those of the Economic Research Service or the U.S. Department of Agriculture.

cropland at a rate no greater than the agronomic nutrient demand of the crops grown on that land, inclusive of commercial fertilizer applications. We couch these policy options in terms of agri-environmental "carrots" and regulatory "sticks," respectively.

The U.S. agricultural sector is likely to respond to these carrots and sticks in a variety of ways. A well-developed literature has examined the effects of agri-environmental payments for crop producers and their potential to reduce the environmental impacts of agricultural production (see, e.g., Cooper and Keim, 1996; Horan and Claassen, 2001). Recent national-level studies have also explored the implications of new water quality regulations for livestock and poultry production (USDA/NRCS, 2003; Kaplan, Johansson, and Peters, 2003; U.S. EPA, 2001; Food and Agricultural Policy Research Institute, 2001). These latter studies predict adverse economic impacts for affected AFOs, improved water quality, and increased commodity prices.

Notably missing from the literature are analyses of how these alternative approaches for improving water quality might interact across regions and across crop, livestock, and poultry sectors. Recent analyses have considered how agri-environmental payments might affect water quality markets (Horan, Shortle, and Abler, 2003) or might interact with other conservation programs, such as Sodbuster (Giannakas and Kaplan, 2001). However, to the best of our knowledge, no previous study investigates the regional interaction of agri-environmental payments and water quality regulation in an endogenous animal and crop production setting.

For example, a corn producer in Iowa might receive agri-environmental payments in return for a reduced nitrogen fertilization regime. At the same time, a nearby swine CAFO might be willing to purchase the right to spread manure on that farmer's fields at the greatest extent allowable under a nutrient standard. In addition, because manure nutrients are not packaged as uniformly as commercial fertilizers, contain pathogens, and are generally more difficult to handle (Risse et al., 2001), crop producers may be reluctant to accept manure nutrients in lieu of commercial fertilizers. The willingness of producers to substitute manure nutrients for commercial fertilizers could play an important role in the effectiveness of carrot-and-stick approaches for achieving water quality improvements.

The potential interactions between and adjustments of crop and animal producers, given these sometimes competing carrot-and-stick incentives, could also generate secondary price impacts. In such cases, Berck and Hoffman (2002) suggest a sector-wide assessment of economic adjustments. Moreover, because the impetus for these policies is to reduce adverse impacts on the environment from agricultural production, we conduct a regional and sector-wide assessment of potential economic and environmental implications.

Analysis findings suggest meeting nutrient standards would result in decreased levels of animal production, increased prices for livestock and poultry products, increased levels of crop production, and water quality improvements. However, estimated impacts are not homogeneous across regions or sectors. In regions with relatively less cropland per ton of manure produced, the impacts of agri-environmental policies are likely to be more pronounced. Impacts are generally smaller the more willing crop producers are to substitute manure nutrients for commercial fertilizers, and are generally larger the more animal feeding operations must meet nutrient standards.

Turning to the potential impacts on water quality, results of this analysis indicate surface water quality improves under the various scenarios considered. Overall, nitrogen discharge to ground and surface water falls by as much as 12.6%, phosphorus discharge falls by more than 30%, sheet and rill erosion falls by 6.7%, and pesticide discharge falls by 5%.

In several regions, however, there are unanticipated economic and water quality impacts. In some cases, agri-environmental payments to crop, livestock, and poultry producers may restrict animal production. Moreover, the discharge of some agricultural pollutants may increase under some carrot-and-stick policies. Specifically, by requiring the spread of manure nutrients at no greater than agronomic rates, nitrogen leaching to groundwater may increase, and so may the discharge of sediment and pesticides to surface water in certain areas. Our results suggest that the use of agri-environmental payments to encourage the adoption of relatively benign crop production practices has the potential to offset many of these unexpected consequences.

The section below presents a regionalized sector model and illustrates the expected changes in agricultural production and prices given the imposition of land application constraints for manure nutrients in the presence of increasing agri-environmental payments. The next section describes the empirical analysis of carrot-and-stick approaches to managing water quality impairments from agricultural production. Simulation results are then presented for several scenarios, detailing the potential changes in market conditions, animal and crop sectors, and water quality. We conclude with a summary of findings and potential implications of key parameters for improving U.S. water quality.

Simulation Analysis

Those AFOS meeting nutrient standards spread the manure they generate on cropland at agronomic rates, or dispose of the manure in some other acceptable manner. When confined animal production within a region generates manure nutrients in excess of the assimilative capacity of the cropland, it can choose to find additional cropland for spreading, plant crops that consume more nutrients, raise animals that produce fewer manure nutrients, or reduce the number of animals produced.

Consider a national market for a representative livestock product with conventional supply and demand functions. The imposition of manure nutrient standards will result in increased costs of production for this product, reflecting nonlinear costs of manure management. In addition, due to increasing output prices for substitute goods throughout the animal sectors, demand shifts outward, establishing a new market-clearing quantity. The availability of agri-environmental payments further alters this market. Government payments lessen the supply contraction, and with similar responses throughout the livestock and poultry markets, the demand for this representative animal product will also shift.

We expect that agri-environmental payments will reduce the market displacement which would have occurred after the imposition of nutrient standards. With respect to higher food prices, consumers are better off when agri-environmental payments are available, but not as well off as when nutrient standards are absent. That said, consumers are also arguably better off when water quality increases. What is less discernable from this illustration is the extent to which animal producers benefit when agri-environmental payments are provided to AFOs who meet nutrient standards. Moreover, some regions will face greater costs than others when meeting nutrient standards, which will result in variable impacts across the United States.

There are many important parameters influencing agricultural sector and environmental responses to water quality regulation and agri-environmental payments. We constrain our analysis to three: nutrient standards (i.e., manure land application restrictions), agri-environmental payments, and manure substitution rates. We first consider a case when only CAFOs meet nutrient standards. For the purposes of this analysis, a CAFO is defined as an AFO with more than 1,000 animal units (Gollehon et al., 2001). These facilities represent 4.47% of the total number of AFOs in the United States, and will soon be required to meet nutrient standards (U.S. EPA, 2002b).[1] The quantity of manure generated by CAFOs exceeds 200 million tons, more than 46% of the total from confined animal operations (table 1).

Regional differences are notable. The percentages of CAFOs in the Southeast and Pacific regions are significantly higher than in other regions. And in the Northern Plains, Appalachia, Mountain, and Pacific regions, CAFOs generate more than 60% of the region's manure on confined animal operations. As adoption of nutrient standards by all AFOs is the stated goal of the USDA (USDA-EPA, 1999), this study also considers the case when CAFOs and an additional 20% of the AFO manure nitrogen and phosphorus produced in a region meet nutrient standards. This essentially reflects an increasing scope of the regulatory stick. Table 1 clearly identifies those regions where meeting nutrient standards might be more difficult than in others. Appalachia, Southeast, and Pacific regions have greater manure generation per acre of cropland than do other regions. Changes in economic performance throughout these regions could be the largest when nutrient standards are imposed due to the relatively high manure-to-cropland acre ratio. Greater environmental improvement in these regions might also be expected.

We next select a range of agri-environmental budgets to represent the carrot approach to inducing water quality improvements. To distribute payments to crop and animal producers based on EQIP provisions, it is assumed that 60% of the budget is allocated to livestock and poultry production to offset fixed and variable costs incurred by livestock and poultry producers when meeting nutrient standards. This includes manure nutrient testing, nutrient management plan development, and manure hauling costs. The remaining 40% of the budget is allocated to crop producers to encourage the adoption of best management practices on their cropland. These practices include residue management,

[1] These regulations use a slightly different definition of "CAFO" than is used in this analysis, defining CAFOs on a head basis by species (rather than by animal units), and include farms where animals are in contact with vulnerable water bodies.

Table 1. Operations with Confined Livestock and Manure Distribution, by USDA Farm Production Region (1997)

USDA Farm Production Region [a]	Operations		Manure (million tons)		CAFO Manure Concentration (tons/acre)
	Total AFO	% CAFO	Total AFO	% CAFO	
Northeast	31,350	1.59	39	15.42	0.42
Lake	52,498	1.64	59	25.10	0.39
Corn Belt	71,252	3.18	73	39.55	0.29
Northern Plains	26,087	4.77	65	64.01	0.57
Appalachia	22,776	7.46	66	62.29	2.25
Southeast	12,635	10.79	23	43.31	1.33
Delta	12,252	7.48	19	39.04	0.42
Southern Plains	10,500	7.00	46	38.22	0.56
Mountain	7,780	8.43	33	69.31	0.80
Pacific	7,654	14.85	40	60.55	2.43
Total United States	254,784	4.47	462	46.36	0.64

Source: 1997 U.S. Census of Agriculture (USDA/NASS, 1999).

[a] States comprising the USDA Farm Production Regions are as follows: Northeast = CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT; Lake = MI, MN, WI; Corn Belt = IA, IL, IN, MO, OH; Northern Plains = KS, ND, NE, SD; Appalachia = KY, NC, TN, VA, WV; Southeast = AL, FL, GA, SC; Delta = AR, LA, MS; Southern Plains = OK, TX; Mountain = AZ, CO, ID, MT, NM, NV, UT, WY; and Pacific = CA, OR, WA.

conservation rotations, and reduced nitrogen fertilization. Three budget levels are examined: $0, $250 million, and $1 billion, to reflect funding levels indicative of authorized EQIP budgets through 2004.

Finally, we choose two manure-nutrient substitution rates over which to conduct the scenarios for this analysis. The willingness to substitute manure nutrients (*substitute*) is defined as the percentage of a region's agronomic demand for nitrogen and phosphorus (based upon crop requirements in that region) met by manure nutrients. Currently, 17% of corn producers and 8% of soybean producers supplement commercial fertilizer with manure as part of their crop fertilization regime [USDA/Economic Research Service (ERS), 2003]. While it is unclear to what extent substitution rates might change as AFOs adopt nutrient standards, it is realistic to assume this rate will increase, especially in regions facing binding nutrient standards. Increasing manure substitution could result from conservation programs such as EQIP or direct purchasing of spreading rights by livestock or poultry producers from crop producers. Therefore, substitution rates are allowed to vary between 20% and 30%.

Six scenarios illustrate the economic and environmental adjustments which may result from a carrot-and-stick approach to improve water quality in the United States. The baseline scenario (*BASE*) corresponds to the USDA forecast for crop and animal production in the year 2010, in the absence of nutrient standards or agri-environmental payments. Results are then presented from the case when crop producers meet 20% of their nutrient needs using manure generated on CAFOs (*C20*). The next two scenarios build on *C20*, by offering agri-environmental payments at the $250 million and $1 billion levels (*C20-25* and *C20-100*), in line with EQIP funding expectations. Next, to reflect increased adoption of manure nutrient applications over time, crop producers are assumed to be willing to meet 30% of the nutrient needs using manure generated on CAFOs in the presence of a $1 billion agri-environmental budget (*C30-100*). Last, holding manure substitution constant at 30% and the budget at $1 billion, we assume an additional 20% of manure nutrients from previously unregulated AFOs are spread according to nutrient standards (*AFO*) to correspond to an increasing scope of the stick.

The Model

To evaluate the implications of meeting nutrient standards, we employ a constrained partial equilibrium, regionalized optimization model of the U.S. agricultural sector, which seeks to maximize profits from livestock, poultry, and crop production in the presence of agri-environmental payments and nutrient standards:

$$\text{(1a)} \quad \max_{\{xact_{rj}, xact_{ri}\}} \sum_j \big(P_j xact_{rj} - VC_{rj} - TC_{rj} - FC_r + AEP_{rj}\big) + \sum_i \big(P_i xact_{ri} - VC_{ri} + AEP_{ri}\big) - AVC_r,$$

subject to:

$$\text{(1b)} \quad \sum_j \big(\theta_{jr} \times man\_nut_{jrf}(xact_{rj})\big) \leq substitute \times Ag\_nut_{rf}(xact_{ri}), \quad \forall r, f$$

and

$$\text{(1c)} \quad \sum_r \sum_j \sum_i \big(AEP_{rj} + AEP_{ri}\big) \leq B.$$

Here, $xact_{rj}$ represents regional production of livestock and poultry species j in region r; $xact_{ri}$ represents regional acres planted under cropping enterprise i (crop rotation and tillage regime) in region r; P_j and VC_j are equilibrium prices and variable costs for livestock and poultry products; and P_i and VC_i are equilibrium prices and variable costs for crops. The model includes fixed costs (FC) essential to meeting a nutrient standard, transportation costs (TC) associated with manure spreading, and additional variable costs (AVC) for soil testing and savings.[2]

Aggregate agri-environmental payments for adopting environmentally benign crop (AEP_{rj}) and animal (AEP_{ri}) production practices are constrained by an exogenously determined budget (B), where B takes on values of \$0, \$250 million, and \$1 billion. Crop producers are paid according to net environmental benefits generated from changing farm management practices. These benefits are broadly calculated to account for potential pollutant loading reductions to surface and groundwater (nutrients, pesticides, and sediments), reduced wind erosion, increased carbon sequestration, and increased soil productivity.

The model is solved iteratively for the imposition of nutrient standards and the use of agri-environmental payments. Because agri-environmental payments are not provided for land retirement under our assumptions, acreage responses occur in the first stage, where the imposition of nutrient standards is modeled. In the second stage, the model is reevaluated in the presence of the agri-environmental payments, holding the acreage response constant.[3] Agri-environmental payments to livestock and poultry producers are assumed to offset fixed and variable costs of nutrient standards.[4]

Transportation costs are a function of the distance traveled and the quantity and type of manure transported. We use conventional estimates of commercial spreading and hauling charges (*Spread* and *Haul*) for tons of manure produced (*Ton*) by animal species within each region, as derived from Borton et al. (1995); Pease, Pelletier, and Kenyon (2001); and Fleming, Babcock, and Wang (1998):

$$\text{(2a)} \quad TC_r = \sum_j Ton_{jr} \times (Spread_{jr} + Dis_r \times Haul_{jr}),$$

where *Dis* is the average distance greater than a mile traveled to spread manure. To calculate the regional distance per affected AFO, we modify the Fleming, Babcock, and Wang methodology for search acreage:

$$\text{(2b)} \quad Dis_r = \sqrt{\frac{Ac_r}{(1 - \gamma_r) \times TO_r \times 640}} - 1,$$

where Ac_r is the total acres available for spreading manure, which is a function of the nutrient standard and the endogenous crop acreage choice ($xact_{ri}$); $\gamma \in (0, 1]$ describes the spatial concentration of affected CAFOs within a region; and *TO* is the total number of AFOs in that region. Here, γ approaches one as the number of affected AFOs within a region increases, effectively centralizing the location of affected operations toward the middle of the region. This, in effect, addresses the land competition effect by allowing the search algorithm to capture the greater distance needed to spread manure from a few highly concentrated operations. Because the farm production regions are already large, transportation of manure is assumed to occur only within a region.

The nutrient standards (1b) require the sum of each manure nutrient generated by animal production activity j within region r (man_nut_{jrf}) to be less than or equal to the product of the regional substitution rate and agronomic crop nutrient demand

---

[2] We do not include all the costs livestock and poultry producers might face as they adjust to meet nutrient standards. Additional costs might include relocation costs, and investments in new storage and handling infrastructure.

[3] Additional acreage responses due to agri-environmental programs may occur at the farm level. However, due to the regional scale of our model, we are unable to portray these adjustments here.

[4] At lower budget levels, EQIP payments to livestock and poultry producers are subsumed by increases in fixed and variable costs of compliance on CAFOs. We incorporate the effect of high conservation budgets by assuming additional AFOs will voluntarily meet nutrient standards using EQIP payments (*AFO* scenario).

($Ag\$nut_{rf}$), where f indexes *nitrogen* and *phosphorus*, respectively. Estimates of available manure nutrients by animal type are net the losses attributable to prevailing storage and handling technology (Kellogg et al., 2000). Agronomic demand is calculated using crop uptake values for nitrogen and phosphorus, accounting for losses due to denitrification, subsurface flow, runoff, and leaching. The affected AFO portion of available manure generation for each region and species is represented by θ_{jr}. Note that $man\$nut_{jrf}$ and $Ag\$nut_{rf}$ are endogenously determined given optimal levels of animal and crop production.

This constrained optimization problem is simulated using the U.S. Regional Agricultural Sector Model (USMP). The model accounts for production of major crop (corn, soybeans, sorghum, oats, barley, wheat, cotton, rice, hay, and silage) and confined animal (beef, dairy, swine, and poultry) categories, comprising approximately 75% of agronomic production and more than 90% of livestock and poultry production (USDA/NASS, 1999).

The USMP is a comparative-static, spatial, and market equilibrium model that incorporates agricultural commodity, supply, demand, environmental impacts, and policy measures (House et al., 2000). This model has been applied to various issues, such as climate change mitigation (Peters et al., 2001), water quality policy (Ribaudo et al., 2001; Greenhalgh and Sauer, 2003), and wetlands policy (Claassen et al., 1998). The model permits the agricultural sector to adjust to the nutrient standards by substituting across production activities, and cropping and tillage practices with varying input requirements. This substitution is facilitated by nested constant elasticity of transformation functions allowing for interior solutions across activities and technologies.

Crop and animal production choices are linked to edge-of-field environmental variables using the Environmental Policy Integrated Climate Model (EPIC), which uses a daily time step to simulate weather, hydrology, soil temperature, erosion-sedimentation, nutrient cycling, tillage, crop management and growth, and pesticide movements to the field's edge (Mitchell et al., 1998). The transport of nutrients, pesticides, and sediment across the landscape is then calibrated to U.S. Geological Survey (USGS) estimates of regional pollutant loads (Smith, Schwartz, and Alexander, 1997).

Estimates of CAFO and AFO spreading practices on swine operations (taken from Ribaudo, Gollehon, and Agapoff, 2003) allow us to account for prior land application of manure in the simulations. Accordingly, CAFOs are assumed to spread manure on the nearest 155 acres, and the smaller AFOs are assumed to spread manure on the nearest 90 acres. While these numbers are not representative of the variety of animal operations across the United States, we argue that these values are reasonable for initial estimates of the environmental effects of excess manure utilization at the Farm Production Region scale. The above levels provide a lower bound on the estimated benefits from meeting nutrient standards since many livestock facilities have little or no land on which to dispose manure. Given the acres currently receiving manure nutrients, we calculate the quantity of manure nutrient in excess of the crop requirements on those acres. These excess nutrients are available for potential leaching into ground waters and/or transport across the landscape into surface waters.

Results

We obtain results portraying a potential range of national and regional changes in the U.S. agricultural sector following the application of agri-environmental carrots and regulatory sticks for water quality improvement by simulating various manure nutrient substitution rates for commercial fertilizers. The results suggest some of the costs of complying with nutrient standards will be passed along to consumers through higher retail meat, dairy, and poultry prices, with or without the presence of agri-environmental payments. In addition, changes in crop and animal production will vary regionally given pre-carrot and pre-stick production levels. Changing production patterns in agriculture will have subsequent impacts on regional water quality depending on underlying land and water characteristics.

Prices and Quantities

Under all scenarios, livestock and poultry prices increase and quantities decrease (table 2). The largest price changes occur in the poultry sector (e.g., 6.3% increase in the price of eggs), and the greatest production changes occur in the swine sector (e.g., 3.2% decrease in production).[5] When

[5] Price changes will also be a function of the embedded elasticities underlying the USMP model. These elasticities are specified so that model supply response at the national level is consistent with supply response in the USDA's Food and Agriculture Policy Simulator (McDowell et al., 1989), an econometric estimated national-level simulation model of the U.S. agriculture sector.

Table 2. Changes in Commodity Prices and Quantities, by Scenario

	Scenario [a]					
Description	*BASE*	*C20*	*C20-25*	*C20-100*	*C30-100*	*AFO*
Prices ($):						
Corn (bu.)	2.60	!0.04	!0.02	0.00	0.02	0.01
Soybeans (bu.)	6.30	!0.07	!0.05	!0.04	0.01	!0.02
Eggs (dozen)	0.69	0.04	0.05	0.05	0.02	0.03
Fluid Milk (cwt)	0.14	0.00	0.00	0.00	0.00	0.00
Fed Beef (cwt)	335.42	1.89	1.70	0.82	0.34	0.59
Pork (cwt)	263.00	3.84	3.87	3.61	0.77	1.62
Quantities (mil. units):						
Corn (bu.)	11,235.38	!84.32	!122.69	!158.85	!93.09	!122.13
Soybeans (bu.)	3,245.04	35.32	17.24	!1.69	!16.95	!6.98
Eggs (dozen)	7,585.81	!26.62	!27.98	!29.84	!9.47	!17.20
Fluid Milk (cwt)	93,463.46	!517.48	!534.04	!542.38	!259.44	!431.41
Fed Beef (cwt)	149.66	!3.40	!3.06	!1.47	!0.62	!1.06
Pork (cwt)	189.82	!5.92	!5.98	!5.57	!1.19	!2.50

Note: The changes are computed relative to the USDA baseline projections for the year 2010 (USDA/World Agricultural Outlook Board, 2001).

[a] Definitions of scenarios are as follows: *C20* represents the scenario in which crop producers meet 20% of nutrient needs with manure; *C20-25* is as *C20*, but with agri-environmental payments of $250 million; *C20-100* is as *C20*, but with agri-environmental payments of $1 billion; *C30-100* is as *C20-100*, but when crop producers meet 30% of nutrient needs with manure; and *AFO* is as *C30-100*, but with an additional 20% of previously unregulated manure spread according to manure standards.

agri-environmental payments increase, the individual sectors respond differently: amplifying the price and quantity changes in the poultry, dairy, and swine sectors, but muting the changes in the beef sector. When manure substitution rates increase, the impacts of nutrient standards on market conditions are lessened.

While price and production changes are examined in 10 major U.S. crop categories, our presentation is restricted to the largest two: corn and soybeans. The accompanying price and quantity changes for these crop sectors are not as large (less than 2% across all scenarios) nor as general as are those for the animal sectors. This is in part due to the dual role of cropland as a sink for manure nutrients and a source of feed grains for livestock and poultry operations. This sink role creates an incentive to plant crops that consume relatively high quantities of phosphorus (assuming the phosphorus constraint is the more limiting nutrient).

For example, note that the quantity of corn produced falls, as does its price under the *C20* and *C20-25* scenarios. This market outcome occurs because the derived demand for corn as an ingredient in feed rations decreases more than the increase in demand for corn acreage as a means of disposal. The relatively large decrease in pork production, a major user of corn, lends support to this result. In addition, corn production is associated with relatively high levels of sediment discharge, and increasing payments to crop producers in exchange for adopting environmentally benign production practices induces a movement away from corn rotations. This supply response to agri-environmental payments in turn lessens the decline in the price for corn. Conversely, even though the price of hay falls, production increases. One explanation for this result is that hay is a relatively high consumer of (i.e., sinks for) phosphorus, which outweighs the reduction in derived demand for hay as a source of feed.

Regional Responses

Under most of the simulated scenarios, planted crop acreage declines marginally across the regions (less than 1%); however, cropland acres increase in the Southeast, Appalachia, and Pacific regions (table 3). These responses reflect an increase in demand for nutrient sinks in these regions, confirming our expectation that those regions with relatively high levels of manure generation per acre of cropland would experience the greatest changes in production. For regions in which livestock and poultry production increase under the *C20* scenario, an initial increase in agri-environmental payments (*C20-25*) would further increase production. If

Table 3. Regional Changes in Crop, Livestock, and Poultry Production, by Scenario (%)

USDA Farm Production Region [a]	Scenario [b]					
	BASE	*C20*	*C20-25*	*C20-100*	*C30-100*	*AFO*
Crops (mil. acres):						
Northeast	14.34	!0.08	!0.08	!0.08	!0.04	!0.06
Lake	38.10	!0.35	!0.35	!0.35	!0.14	!0.25
Corn Belt	99.04	!0.50	!0.50	!0.50	!0.20	!0.34
Northern Plains	72.79	!0.37	!0.37	!0.37	!0.15	!0.25
Appalachia	18.33	1.74	1.74	1.74	0.66	1.24
Southeast	7.57	0.97	0.97	0.97	0.37	0.77
Delta	17.39	!0.10	!0.10	!0.10	!0.04	!0.08
Southern Plains	31.73	0.21	0.21	0.21	!0.02	!0.04
Mountain	28.26	!0.08	!0.08	!0.08	!0.04	!0.06
Pacific	9.86	0.60	0.60	0.60	0.27	0.42
Total United States	337.42	2.03	2.03	2.03	0.67	1.36
Confined Livestock & Poultry (mil. animal units):						
Northeast	2.45	0.22	0.22	0.22	0.07	0.12
Lake	6.07	0.59	0.63	0.62	0.18	0.31
Corn Belt	11.06	1.47	1.48	1.48	0.34	0.72
Northern Plains	16.93	0.24	0.82	0.77	0.24	0.35
Appalachia	8.93	!3.52	!3.58	!3.58	!0.97	!1.81
Southeast	0.46	!0.13	!0.13	!0.13	!0.04	!0.09
Delta	0.45	0.05	0.06	0.06	0.02	0.03
Southern Plains	10.23	0.11	!0.20	!0.18	!0.03	0.08
Mountain	6.54	!0.05	0.26	0.23	0.11	0.11
Pacific	3.81	!0.87	!0.90	!0.90	!0.34	!0.59
Total United States	66.93	!1.90	!1.35	!1.42	!0.43	!0.78

Note: The regional changes are computed relative to the USDA baseline projections for the year 2010 (USDA/World Agricultural Outlook Board, 2001).

[a] States comprising the USDA Farm Production Regions are as follows: Northeast = CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT; Lake = MI, MN, WI; Corn Belt = IA, IL, IN, MO, OH; Northern Plains = KS, ND, NE, SD; Appalachia = KY, NC, TN, VA, WV; Southeast = AL, FL, GA, SC; Delta = AR, LA, MS; Southern Plains = OK, TX; Mountain = AZ, CO, ID, MT, NM, NV, UT, WY; and Pacific = CA, OR, WA.

[b] Definitions of scenarios are as follows: *C20* represents the scenario in which crop producers meet 20% of nutrient needs with manure; *C20-25* is as *C20*, but with agri-environmental payments of $250 million; *C20-100* is as *C20*, but with agri-environmental payments of $1 billion; *C30-100* is as *C20-100*, but when crop producers meet 30% of nutrient needs with manure; and *AFO* is as *C30-100*, but with an additional 20% of previously unregulated manure spread according to manure standards.

agri-environmental payments further increased (a movement from *C20-25* to *C20-100*), production would begin to fall. The opposite response occurs in those regions where animal production initially falls following the imposition of the initial nutrient standard (*C20*).

It seems counterintuitive that providing agri-environmental payments to crop, livestock, and poultry producers, all else constant, would lead to lower animal production. One explanation for this result is that the agri-environmental payments to crop producers for the adoption of environmentally benign production systems might induce movement toward crop rotations not demanding large amounts of phosphorus and nitrogen. Movement to these alternative crop mixes would serve to make the nutrient application standards more difficult to meet for those affected AFOs, essentially decreasing the availability of manure nutrient sinks. However, at higher levels of agri-environmental payments, crop producers appear to be adopting management practices, such as residue management, which do not focus as much on crop rotations. Hence, the production responses are marginal.

Sector Responses

The changes in national-level prices and quantities translate into differing regional responses as expected. Corresponding adjustments in net returns

Table 4. Regional Changes in Agricultural Net Returns, by Scenario ($ millions)

USDA Farm Production Region	SCENARIO					
	BASE	*C20*	*C20-25*	*C20-100*	*C30-100*	*AFO*
Crops:						
Northeast	1,100.01	!22.46	!3.37	27.29	41.81	51.48
Lake	3,267.23	!90.60	6.55	138.19	170.15	174.31
Corn Belt	16,399.14	!429.36	!205.14	70.52	314.78	228.11
Northern Plains	5,119.94	!52.43	33.70	187.93	226.47	220.03
Appalachia	1,824.90	15.22	!17.29	13.74	94.28	67.14
Southeast	593.68	44.79	18.31	16.13	46.49	35.75
Delta	806.23	!11.71	17.10	68.64	79.27	87.12
Southern Plains	1,221.11	8.73	39.39	101.11	132.53	149.73
Mountain	1,610.96	6.00	23.71	55.27	66.49	67.73
Pacific	792.62	!65.03	!37.84	19.18	83.30	61.19
Total United States	32,735.82	!596.85	!124.86	698.01	1,255.57	1,142.58
Livestock & Poultry:						
Northeast	3,709.48	460.34	461.78	460.91	133.35	228.10
Lake	3,973.47	457.55	466.19	485.44	110.32	195.99
Corn Belt	3,608.07	770.20	779.30	796.34	128.26	325.47
Northern Plains	3,212.53	133.52	188.19	354.05	!7.55	48.31
Appalachia	3,183.93	!38.22	!40.99	!28.14	!6.96	!49.28
Southeast	3,008.05	!624.87	!636.70	!650.02	!133.96	!429.62
Delta	2,334.03	341.30	339.09	339.57	61.27	171.41
Southern Plains	3,641.18	239.72	205.74	146.18	79.93	177.44
Mountain	2,310.30	173.86	200.82	278.34	73.12	101.15
Pacific	4,490.48	!1,105.51	!1,105.57	!1,096.42	!487.88	!651.45
Total United States	33,471.53	807.88	857.85	1,086.23	!50.10	117.51

Notes: The regional changes are computed relative to the USDA baseline projections for the year 2010 (USDA/World Agricultural Outlook Board, 2001). Refer to table 3 (footnotes a and b, respectively) for listing of states comprising the USDA Farm Production Regions and definitions of scenarios.

are not as straightforward. At lower manure substitution rates, the price impacts are sufficient to compensate aggregate decreases in livestock and poultry production (table 4). Nationally, net returns increase with increasing agri-environmental payments. When manure substitution rates are at 30%, the price effect no longer dominates the production (and carrot) effect, and national net returns to animal production fall. However, by increasing the scope of the stick (the *AFO* scenario), the price effect in conjunction with higher levels of agri-environmental payments results in increasing net returns (over the *BASE* scenario) for the livestock and poultry sectors.

The crop sector results are nearly opposite of the livestock and poultry sector results. Initially, aggregate net returns fall due to the decrease in prices, which are relatively larger than the increase in total acreage planted. However, as agri-environmental payments increase or as manure substitution rates increase, the change in crop returns becomes positive. Note that, under our assumptions, the agricultural sector as a whole might experience increases in net returns by amounts greater than the agri-environmental budget.

This finding does not suggest all sectors or regions will share in these increased returns. Taking a closer look at the 10 regions, we observe that in many instances net returns fall as the carrot grows and the scope of the stick widens. Falling net returns for livestock and poultry production are especially evident in the Southeast, Appalachia, and Pacific regions, and do not seem to be affected by increasing availability of agri-environmental payments. Actually, initial offerings of agri-environmental payments appear to lead to marginally lower net returns—indicating, in these regions, the agri-environmental incentives to produce crops using systems that consume relatively fewer nutrients are greater than the incentives to provide animal producers with nitrogen and phosphorus sinks. Even at high levels of agri-environmental payments, net returns to animal production in the Southeast continue to fall.

Based on these results, a question is raised about the overall impact of agri-environmental payments on net returns when prices are allowed to adjust. The transfer efficiency for animal production is less than 60% under the various scenarios, implying that even though animal producers are assisted in complying with nutrient standards by agri-environmental payments, the subsequent price effects mute the impact of carrots on net returns. Initially, the transfer efficiency for livestock and poultry producers is only 33%. Specifically, under *C20-25*, a $150 million (i.e., 60% of $250 million) transfer to livestock and poultry producers to assist in compliance results in an increase in net returns of $50 million. This transfer efficiency rises to 51% under *C20-100*, when an additional $450 million in agri-environmental payments are allocated to livestock and poultry producers.

Conversely, the transfer efficiency of agri-environmental payments to crop producers is much higher than for animal producers incorporating price adjustments, exceeding 100% in our policy scenarios. Under *C20-25*, a transfer of $100 million to crop producers results in a more than fourfold increase in net returns (i.e., from ! $596.85 million to ! $124.86 million). An additional transfer of $300 million in agri-environmental payments to crop producers under *C20-100* results in a gain of $573.15 in net returns, a transfer efficiency of 191%.

In looking at the national totals for both crop and animal sectors, a $250 million investment in our agri-environmental program yields an increase in net revenues of more than $700 million when coupled with the regulatory stick at the lower manure substitution rates. These estimates include the potential savings in commercial fertilizer costs, potential costs incurred in meeting nutrient standards and in providing agri-environmental benefits, potential impacts of price and production changes, and transfer effects of agri-environmental payments. At the higher budget, national net returns increase by more than $1.7 billion for agriculture as a whole. At higher manure substitution rates and when more AFOs meet nutrient standards (i.e., *C30-100* and *AFO*), increases in net returns are not as high as under the *C20-100* scenario, yet they still exceed $1 billion.

Environmental Impacts

The use of EPIC allows us to examine the environmental implications resulting from our carrot-and-stick scenarios. In particular, we estimate the potential quantity of nitrogen discharged into surface and groundwater (table 5), and the potential quantities of three additional contaminants discharged into surface water—phosphorus, sediment, and pesticides (table 6).

The potential changes in the discharge of nitrogen to surface waters and leaching of nitrogen to groundwater listed in table 5 reveal some unintended effects of our carrot-and-stick scenarios for improving water quality. Across all regions and scenarios, the amount of nitrogen discharged to surface waters falls from the pre-carrot-and-stick scenario. Nationally, these reductions range from 10% to 16%. Increasing the scope of the stick and the size of the carrot leads to larger reductions, although greater manure substitution rates mute this response.

Nitrogen leaching increases under the *C20* scenario, but falls with increasing agri-environmental payments and increasing manure substitution. A broadening of the scope of the stick from the *BASE* scenario to *C20*, or from *C30-100* to *AFO*, results in a more binding nutrient standard, creating an incentive to expand cropland acres and adjust acreage share in favor of crops that consume relatively more nutrients and leach more nitrogen, particularly in the Southeast, Appalachia, and Pacific regions. Because the phosphorus constraint is more binding than the nitrogen constraint, crop producers will have to supplement the new cropping patterns with additional commercial nitrogen fertilizer, which serves to undermine the reductions in manure production.

For example, a closer examination of the potential adjustments occurring in the Pacific region reveals a general expansion in crop production across the scenarios, especially in corn and hay production. Both of these crops exhibit relatively high levels of nitrogen leaching. Furthermore, in areas of California, the potential expansion in cropland and in cotton, rice, and barley production results in elevated levels of nitrogen leaching. Nevertheless, the nitrogen prevented from reaching surface waters is of a greater magnitude than the relatively small increases in nitrogen leaching across all regions and scenarios. Overall, the reduction in nitrogen discharged to ground and surface waters ranges from 6.2% to12.6%.

As for other measures of potential water quality impairment (table 6), changes in phosphorus loading are observed to follow the same pattern as nitrogen discharged to surface water, with reductions in phosphorus ranging from 24.8% to 37.6%. The

Table 5. Regional Changes in Nitrogen Discharge, by Scenario

USDA Farm Production Region	SCENARIO					
	BASE	*C20*	*C20-25*	*C20-100*	*C30-100*	*AFO*
Runoff into Surface Water (mil. lbs.):						
Northeast	193.69	!21.98	!25.49	!29.08	!27.74	!28.37
Lake	393.99	!40.26	!48.12	!59.09	!54.31	!56.48
Corn Belt	1,525.23	!50.14	!152.14	!180.70	!169.57	!175.51
Northern Plains	440.14	!38.83	!46.71	!55.27	!49.80	!52.16
Appalachia	358.14	!54.68	!60.28	!76.25	!79.10	!76.93
Southeast	182.57	!53.46	!54.78	!55.80	!64.28	!58.42
Delta	252.56	!12.08	!15.58	!21.01	!25.45	!26.45
Southern Plains	266.41	!12.82	!17.51	!23.66	!27.00	!32.04
Mountain	162.54	!44.08	!45.60	!47.86	!46.83	!47.19
Pacific	170.05	!77.45	!77.80	!79.17	!81.16	!80.21
Total United States	3,945.31	!405.78	!544.02	!627.88	!625.24	!633.77
Leaching into Groundwater (mil. lbs.):						
Northeast	130.01	!1.33	!3.61	!8.13	!5.63	!6.71
Lake	357.33	!12.35	!30.97	!51.60	!38.97	!44.49
Corn Belt	234.60	!1.39	!8.12	!13.55	!12.49	!12.84
Northern Plains	112.65	!1.18	!4.66	!9.97	!8.44	!9.13
Appalachia	401.53	35.27	29.10	18.14	2.90	11.19
Southeast	182.63	19.40	16.46	14.10	2.40	10.44
Delta	141.20	!2.28	!8.60	!16.46	!13.52	!14.85
Southern Plains	62.90	0.80	!2.22	!6.26	!8.00	!8.69
Mountain	31.48	!0.12	!1.37	!2.88	!2.35	!2.55
Pacific	54.98	17.67	11.95	1.84	!6.24	!2.76
Total United States	1,709.32	54.49	!2.04	!74.77	!90.34	!80.39

Notes: The potential regional changes are computed relative to the USDA baseline projections for the year 2010 (USDA/World Agricultural Outlook Board, 2001). Refer to table 3 (footnotes a and b, respectively) for listing of states comprising the USDA Farm Production Regions and definitions of scenarios.

results indicate that increasing the scope of the stick, the size of the carrot, and the manure substitution rates all contribute to reduced phosphorus discharge. However, as with nitrogen leaching, the quantities of sediment and pesticides discharged into surface waters increase in the absence of agri-environmental payments. As agri-environmental payments increase, loadings of sediment and pesticides fall. The change in soil erosion ranges from !0.7% to 6.7%, and pesticide-loading change ranges from !0.9% to 5.5%.

Soil erosion is greatest at the lower manure substitution rate under the smaller stick (*C20-100*). That is, by relaxing the constraints on spreading manure nutrients (moving from *C20-100* to *C30-100*), less land leaves production in regions with decreased crop production (e.g., the Corn Belt) and less land comes into production in regions with increased crop production (e.g., the Pacific). The relative changes in soil erosion rates across these regions would result in an additional 330,000 tons of sediment being discharged under *C30-100* relative to *C20-100*. The amount of pesticide discharged to surface waters declines with increasing agri-environmental payments, with increasing acceptance of manure nutrients, and with an increasing scope of manure nutrient standards for AFOs. These reductions range between !0.9% under the *C20* scenario and 5.5% under the *AFO* scenario.

Summary of Agricultural Sector Analysis

A number of efforts at the local, state, and federal levels aim to reduce potentially adverse impacts of agricultural production on the environment in general and on water quality in particular. Some trends that are illustrative of these efforts include carrot approaches (the increased level of support in recent Farm Bill legislation for crop, livestock, and poultry producers to implement environmentally benign production practices) and stick approaches (the recently promulgated rules for manure nutrients

Table 6. Additional Regional Changes to Surface Water Quality, by Scenario

USDA Farm Production Region	SCENARIO					
	BASE	*C20*	*C20-25*	*C20-100*	*C30-100*	*AFO*
Phosphorus Discharge (mil. lbs.):						
Northeast	17.73	!1.17	!1.32	!1.42	!3.62	!4.42
Lake	27.67	!3.38	!3.40	!3.33	!8.20	!9.95
Corn Belt	130.04	!9.61	!17.94	!19.91	!33.55	!35.96
Northern Plains	38.25	!9.34	!9.72	!9.57	!11.57	!12.82
Appalachia	56.33	!27.98	!28.40	!29.42	!28.44	!30.34
Southeast	32.32	!14.23	!14.33	!14.45	!12.03	!14.52
Delta	23.22	!2.44	!2.67	!2.93	!4.35	!5.66
Southern Plains	30.62	!5.84	!6.40	!7.36	!7.23	!9.53
Mountain	20.33	!10.93	!10.69	!9.87	!11.14	!12.33
Pacific	17.83	!12.96	!12.98	!13.01	!11.66	!12.89
Total United States	394.35	!97.88	!107.83	!111.26	!131.78	!148.42
Sheet and Rill Erosion (mil. tons):						
Northeast	7.84	!0.04	!0.25	!0.46	!0.42	!0.44
Lake	20.30	!0.22	!0.65	!1.24	!1.02	!1.13
Corn Belt	101.87	!0.67	!8.45	!10.68	!9.80	!10.28
Northern Plains	14.85	!0.19	!0.62	!1.04	!0.83	!0.92
Appalachia	12.08	1.04	0.74	!0.48	!0.38	!0.35
Southeast	12.12	1.41	1.33	1.23	0.32	0.94
Delta	9.72	!0.05	!0.18	!0.34	!0.26	!0.30
Southern Plains	17.47	0.25	!0.11	!0.65	!1.07	!1.23
Mountain	12.01	!0.01	!0.20	!0.59	!0.46	!0.51
Pacific	4.55	0.06	0.02	!0.02	!0.04	!0.02
Total United States	212.81	1.58	!8.36	!14.27	!13.95	!14.21
Pesticide Discharge (mil. TPUs): [a]						
Northeast	8,538.50	!49.00	!131.70	!268.80	!201.10	!230.80
Lake	27,216.50	!354.50	!877.60	!1,451.50	!1,151.90	!1,292.60
Corn Belt	102,671.10	!938.30	!2,062.00	!3,168.40	!2,332.20	!2,675.30
Northern Plains	21,573.80	!534.60	!454.10	!344.20	!32.30	!178.30
Appalachia	24,024.00	253.60	!142.90	!739.90	!678.70	!636.00
Southeast	17,847.10	908.00	823.30	704.80	142.90	524.50
Delta	61,899.20	!67.80	!376.00	!271.00	!115.80	!162.80
Southern Plains	103,245.70	588.90	!5,094.30	!20,305.40	!21,047.50	!25,177.90
Mountain	108,813.30	!1,028.90	!2,526.60	!3,939.60	!3,112.50	!3,502.50
Pacific	54,172.60	5,933.10	5,954.20	6,017.40	2,738.90	4,219.00
Total United States	530,001.80	4,710.50	!4,897.70	!23,766.50	!25,790.20	!29,112.70

Notes: The potential regional changes are computed relative to the USDA baseline projections for the year 2010 (USDA/World Agricultural Outlook Board, 2001). Refer to table 3 (footnotes a and b, respectively) for listing of states comprising the USDA Farm Production Regions and definitions of scenarios.
[a] TPUs refer to "toxicity persistence units" (Barnard et al., 1997). As a point of reference, the number of TPUs in a pound of DDT = 4,443 million and in a pound of Borax = 103,872.

generated on CAFOs). This study analyzes potential economic and environmental implications of these carrot-and-stick approaches to improving the quality of U.S. water resources. In addition, we consider how the willingness of crop producers to substitute manure nutrients for commercial fertilizers might influence the changes brought about by carrot-and-stick policies. These parameters form the basis of six potential scenarios depicting how agri-environmental payments, the scope of manure nutrient standards, and manure substitution rates might evolve in the United States.

First, we compare results when no payments or nutrient standards exist with the scenario where crop producers are willing to meet 20% of their crop nutrient demand using manure (*BASE* to *C20*). Building on this scenario, the effect of providing agri-environmental payments to crop and livestock producers is evaluated, somewhat akin to the Environmental Quality Incentives Program. By increasing the budget from $0 to $250 million to $1 billion, the carrot effect is investigated (scenarios *C20* to *C20-25* to *C20-100*). Two additional scenarios are then examined to see how increasing manure substitution rates and coverage of nutrient standards might differ from our earlier results (*C30-100* and *AFO*).

A wealth of regional- and sector-level results emerge from these scenarios, illustrating how agri-environmental policies might affect agricultural production and improve water quality in the United States. In general, carrots and sticks result in decreasing levels of animal production, increasing levels of crop production, and increasing prices for livestock and poultry products. In particular, poultry and dairy products could see substantial price increases when the willingness of crop producers to substitute manure nutrients remains low. Nevertheless, adverse impacts on net returns to both crop and animal producers can be mitigated by providing increasing agri-environmental payments.

For example, without agri-environmental payments (*C20*), six of ten regions experience decreasing net returns to crop production; however, by including $400 million in agri-environmental payments for crop producers (*C20-100*), all regions experience increasing net returns to crop production. For those regions that experience adverse impacts on net returns to animal production (the Southeast, Appalachia, and Pacific), it appears the willingness of crop producers to substitute manure nutrients has the most bearing on reducing these losses. Because net returns for crop producers also increase with increasing manure substitution, use of carrots to induce crop producers to utilize more manure nutrients may represent an avenue for future inquiry.

Results indicate agri-environmental payments can offset some unintended consequences of the nutrient standards on water quality. Specifically, by requiring certain AFOs to spread manure nutrients at no greater than agronomic rates, there is potential in some regions to increase both nitrogen leaching to groundwater and increase discharge of sediment and pesticides to surface water due to changing crop levels and composition. However, when agri-environmental payments to crop producers are used to encourage the adoption of environmentally benign production practices, the subsequent reductions in cropland loadings offset any potential increases induced by the nutrient standards. Overall, nitrogen discharge to ground and surface water might fall by as much as 12.6%, phosphorus discharge by more than 30%, sheet and rill erosion by 6.7%, and pesticide discharge to surface waters by more than 5%. While it is beyond the scope of this paper to place a value on the benefits of these reductions, findings suggest coordinating agri-environmental payments and manure spreading regulations can significantly enhance water quality in the United States.

Aggregate analysis of the U.S. agricultural sector cannot reveal how individual operations would benefit or suffer from these trends. However, if only the largest animal feeding operations meet nutrient constraints, the costs of compliance would fall on CAFOs and the benefits from secondary price effects will accrue to smaller AFOs. When crop producers' substitution rates for manure nutrients remain at or near current levels (i.e., a 20% substitution rate), the secondary price effects are sufficient to compensate much of the livestock and poultry sectors for the costs of meeting nutrient standards. However, at higher manure substitution rates, the increased costs of transporting manure, manure testing, soil testing, and developing a manure management plan outweigh compensating price effects and foregone commercial fertilizer purchases, resulting in reduced net returns for the livestock and crop sectors. Also, at higher manure substitution rates, consumers benefit from lower price increases and greater increases in water quality.

References

Barnard, C., S. Daberkow, M. Padgitt, M. E. Smith, and N. D. Uri. (1997). "Alternative Measures of Pesticide Use." *Science of the Total Environment* 203, 229–244.

Berck, P., and S. Hoffman. (2002). "Assessing the Employment Impacts of Environmental and Natural Resource Policy." *Environmental and Resource Economics* 22, 133–156.

Borton, L. R., C. A. Rotz, H. L. Person, T. M. Harrigan, and W. G. Bickert. (1995). "Simulation to Evaluate Dairy Manure Systems." *Applied Engineering in Agriculture* 11(2), 301–310.

Claassen, R., R. E. Heimlich, R. M. House, and K. D. Wiebe. (1998). "Estimating the Effects of Relaxing Agricultural Land Use Restrictions: Wetland Delineation in the Swampbuster Program." *Review of Agricultural Economics* 20, 390–405.

Cooper, J. C., and R. W. Keim. (1996). "Incentive Payments to Encourage Farmer Adoption of Water Quality Protection Practices." *American Journal of Agricultural Economics* 78(1), 54–64.

Fleming, R., B. Babcock, and E. Wang. (1998). "Resource or Waste? The Economics of Swine Manure Storage and Management." *Review of Agricultural Economics* 20(1), 96–113.

Food and Agricultural Policy Research Institute (FAPRI). (2001, July). "FAPRI's Analysis of the EPA's Proposed CAFO Regulations." FAPRI-UMC Report No. 06-01, University of Missouri, Columbia.

Giannakas, K., and J. Kaplan. (2001, August). "(Non)Compliance with Agricultural Conservation Programs: Theory and Evidence." Selected paper presented at annual meetings of the AAEA, Chicago, IL.

Gollehon, N., M. Caswell, M. Ribaudo, R. Kellogg, C. Lander, and D. Letson. (2001). "Confined Animal Production and Manure Nutrients." Agriculture Information Bull. No. 771, USDA/Economic Research Service, Washington, DC.

Greenhalgh, S., and A. Sauer. (2003, February). "Awakening the Dead Zone: An Investment for Agriculture, Water Quality, and Climate Change." Issue Brief, World Resources Institute, Washington, DC.

Horan, R. D., and R. Claassen. (2001). "The Welfare Sensitivity of Agri-Environmental Instruments." *Journal of Agricultural and Resource Economics* 26(2), 368–386.

Horan, R. D., J. Shortle, and D. Abler. (2003, June). "Coordination of Point-Nonpoint Trading Programs and Agri-Environmental Policies." Selected paper presented at the NAREA Workshop on Linkages Between Agricultural and Conservation Policy, Portsmouth, NH.

House, R. M., H. McDowell, M. Peters, and R. Heimlich. (2000). "Agriculture Sector Resource and Environmental Policy Analysis: An Economic and Biophysical Approach." In V. Barnett (ed.), *Environmental Statistics: Analyzing Data for Environmental Policy*. New York: John Wiley and Sons.

Kaplan, J. D., R. C. Johansson, and M. A. Peters. (2003). "National Analysis: Industry Effects of Manure Management." In *Manure Management for Water Quality Improvements: Cost of Land Applying Nutrients from Animal Feeding Operations* (pp. 62–81). Agricultural Economics Report No. 824, USDA/Economic Research Service, Washington, DC.

Kellogg, R. L., C. H. Lander, D. C. Moffitt, and N. Gollehon. (2000). *Manure Nutrients Relative to the Capacity of Cropland and Pastureland to Assimilate Nutrients: Spatial and Temporal Trends for the United States.* USDA/Natural Resources Conservation Service and Economic Research Service, Washington, DC.

McDowell, H., R. Kramer, A. Randall, and M. Price. (1989). "An Analysis of U.S. Farm Income Policies: Historical, Market-Determined, and Sector-Wide Stabilization." *Southern Journal of Agricultural Economics* 21(2), 1–11.

Mitchell, G., R. H. Griggs, V. Benson, and J. Williams. (1998, September). "Environmental Policy Integrated Climate Model (EPIC)." Online. Available at http://www.brc.tamus.edu/epic/.

Pease, J., B. A. Pelletier, and D. Kenyon. (2001, January). "Poultry Litter Transport Alternatives for Land Application in Virginia." Selected paper presented at annual meetings of the SAEA, Ft. Worth, TX.

Peters, M., J. Lewandrowski, R. House, and H. McDowell. (2001). "Economic Impacts of Carbon Charges on U.S. Agriculture." *Climatic Change* 50, 445–473.

Ribaudo, M., N. Gollehon, and J. Agapoff. (2003). "Land Application of Manure by Animal Feeding Operations: Is More Land Needed?" *Journal of Soil and Water Conservation* 58, 30–38.

Ribaudo, M., R. Heimlich, R. Claassen, and M. Peters. (2001). "Least-Cost Management of Nonpoint Source Pollution: Source Reduction vs. Interception Strategies for Controlling Nitrogen Loss in the Mississippi Basin." *Ecological Economics* 37, 183–197.

Risse, L. M., M. L. Cabrerea, A. J. Franzluebbers, J. W. Gaskin, J. E. Gilley, R. Killorn, D. E. Radcliffe, W. E. Tollner, and H. Zhang. (2001). "Land Application of Manure for Beneficial Reuse." White paper, National Center for Manure and Animal Waste Management, Ames, IA.

Smith, R. A., G. E. Schwarz, and R. B. Alexander. (1997). "Regional Interpretation of Water-Quality Monitoring Data." *Water Resources Research* 33, 2781–2798.

U.S. Department of Agriculture, Economic Research Service. (2003). *Agricultural Resources and Environmental Indicators.* Agricultural Handbook No. AH722, USDA/ERS, Washington, DC.

U.S. Department of Agriculture and U.S. Environmental Protection Agency. (1999). "Unified National Strategy for Animal Feeding Operations." USDA/EPA joint policy statement, Washington, DC. Online. Available at http://www.epa.gov/npdes/pubs/finafost.pdf.

U.S. Department of Agriculture, National Agricultural Statistics Service. (1999, March). *1997 Census of Agriculture.* Pub. No. AC97-A-51, USDA/NASS, Washington, DC. Online. Available at http://www.nass.usda.gov/census/.

U.S. Department of Agriculture, Natural Resources Conservation Service. (2002). "Fact Sheet: Environmental Quality Incentives Program." USDA/NRCS, Washington, DC. Online. Available at http://www.nhq.nrcs.usda.gov/CCS/FB96OPA/eqipfact.html.

———. (2003). "Costs Associated with Development and Implementation of Comprehensive Nutrient Management Plans." USDA/NRCS report, Washington, DC.

U.S. Department of Agriculture, World Agricultural Outlook Board. (2001). "USDA Agricultural Baseline Projections to 2010." Staff Report No. WAOB-2001-1, USDA, Office of the Chief Economist, Washington, DC.

U.S. Environmental Protection Agency. (2001). "Environmental and Economic Benefit Analysis of Proposed Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Animal Feeding Operation." Report No. EPA-821-R-01-002, Office of Water, Washington, DC.

———. (2002a). *2000 National Water Quality Inventory.* Report No. EPA-841-R-02-001, Office of Water, Washington, DC.

———. (2002b). "Concentrated Animal Feeding Operations (CAFO)—Final Rule." Environmental Protection Agency, Washington, DC. Online. Available at http://cfpub.epa.gov/npdes/afo/cafofinalrule.cfm.