Appendixes to:

Comparing Participation in Nutrient Trading by Livestock Operations to Crop Producers in the Chesapeake Bay Watershed

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Appendix A: Estimating Head of Animals and Animal Units

The statistics in this report largely arise from accessing restricted-use 2012 Census of Agriculture data at the farm level. For many types of animals, the Census of Agriculture records the number of head in inventory as well as the number of animals sold in the year. While the number of head in inventory may be a good measure of the number of head at livestock operation types that maintain a constant population over the course of the year, it may not be as useful when considering livestock types that see several cycles over a year. For example, the inventory number captured on the Census of Agriculture may provide the number of head at either the top or the bottom of a cycle, or some time in between. We therefore use methods developed by USDA, Natural Resources Conservation Service (NRCS) to characterize types of farms according to livestock confinement and size. The NRCS methodology is described in Kellogg et al. (2000) (hereafter KLMG) and Kellogg, Moffitt, and Gollehon (forthcoming) (hereafter KMG). Variations from KLMG and KMG are described in appendix B. We follow KMG and KLMG to estimate the average number of head on farm over the course of the year using both inventory and sales data.

The general algorithm used to estimate the number of animals of a specific type uses both inventory and sales, as well as assumptions on the number of cycles of production during a year. The general equations for generating the number of animal units come from KLMG. For certain livestock types, both inventory and sales data are used to compute animal units. For these livestock types, the algorithm to estimate the average number of animals on the farm over the course of a year is:

(A1) $$annual\ average\ animals = \left\{\left(inventory \times \frac{1}{cycles}\right) + \left[\frac{sales}{cycles} \times \frac{(cycles - 1)}{cycles}\right]\right\}$$

For farms with just inventory and no sales data, the following algorithm is used:

(A2) $$annual\ average\ animals = \left(inventory \times \frac{1}{2} \times \frac{1}{cycles}\right)$$

For farms with just sales and no inventory data, the following algorithm is used:

(A3) $$annual\ average\ animals = \left(\frac{sales}{cycles}\right)$$

We follow KMG in assuming that certain livestock types are in residence throughout the year, and therefore there is no change in inventory over the production cycle. In these circumstances the number of animals is the just number of animals in inventory:

(A4) $$annual\ average\ animals = inventory$$

Additionally, sales and/or inventory of certain types of livestock are not collected in the Census, but are calculated through a series of equations, detailed in KMG and in appendix B. We use parameters for the number of animals per animal unit and the number of cycles per year from KMG. Most frequently, we use the equations in KLMG but the parameters in the updated document KMG. Appendix table A1 lists the livestock categories for which we follow precisely the equations in KLMG or equations A1-A4 except for updating the parameters according to KMG.

For the livestock categories not listed in appendix table A1, we modify the equations listed in KLMG and use the parameters listed in KMG. Some of these equations are described but not explicitly stated in KMG. For clarity we either state or describe them in appendix B.

After calculating the number of animals at a facility, we generate the number of animal units (AUs). AUs provide a method of normalizing across animal types to enable comparison. This involves multiplying the number of head by a parameter providing the number of animal units per head. Parameters can be found in KMG.

Confined portion of pastured livestock types

Following KMG, we characterize livestock types as "confined" and "pastured" in order to later estimate how much manure from animals can be "recovered" for later application to fields. The livestock types in the column "Confined livestock types" in appendix table A2 are assumed to always be confined. The livestock types in the "Confined or pastured livestock types" column are assumed to be either confined or totally pastured based on the pasture acreage at the farm. Specifically, the number of animal units of this type are summed by farm and then compared to the amount of pastured acreage on farm. A portion of the animal units assumed to be confined according to the ratio of animal units to the amount of pastureland available on the operation:

If $\frac{Animal\ units}{Pasture\ acreage} < 8$ then all of these animal units are assumed to be pastured.

If $8 \leq \frac{Animal\ units}{Pasture\ acreage} < 13$ then 25% of these animal units are assumed to be pastured, and 75% are assumed to be confined.

If $13 \leq \frac{Animal\ units}{Pasture\ acreage} < 18$ then 50% of these animal units are assumed to be pastured, and 50% are assumed to be confined.

If $\frac{Animal\ units}{Pasture\ acreage} \geq 18$ then 75% of these animal units are assumed to be pastured, and 25% are assumed to be confined.

If there is no pasture acreage, all of these animals are assumed to be confined.

Appendix Table A1: Equations and parameters used to generate AUs for certain livestock categories

Livestock category	Equation from KLMG (where applicable)	Sources of data to estimate AUs	Appendix equation used
Milk cows	eq. 6	Year-end inventory	A4
Hogs for breeding	eq. 7	Year-end inventory	A4
Hogs for slaughter – Farrow to wean		Year-end inventory and sales	A1-A3
Hogs for slaughter – Farrow to finish		Year-end inventory and sales	A1-A3
Hogs for slaughter – Finish only		Year-end inventory and sales	A1-A3
Hogs for slaughter – Farrow to feeder		Year-end inventory and sales	A1-A3
Hogs for slaughter – Nursery		Year-end inventory and sales	A1-A3
Breeding turkeys	eq. 13-14	Year-end inventory and sales	A3-A4
Slaughter turkeys	eq. 21-23	Year-end inventory and sales	A1-A3
Chicken broilers	eq. 18-20	Year-end inventory and sales	A1-A3
Chicken pullets		Year-end inventory and sales	A1-A3
Ducks		Year-end inventory and sales	A1-A3
Horses and ponies		Year-end inventory	A4
Mules, burros, and donkeys		Year-end inventory	A4
Sheep and goats		Year-end inventory	A4
Bison		Year-end inventory	A4
Deer		Year-end inventory	A4
Elk		Year-end inventory	A4
Llama		Year-end inventory	A4
Mink		Year-end inventory	A4
Rabbits		Year-end inventory	A2
Emu		Year-end inventory	A4
Geese		Year-end inventory	A2
Ostriches		Year-end inventory	A4
Pheasants		Year-end inventory	A2
Pigeons		Year-end inventory	A2
Quail		Year-end inventory	A2

Notes: KLMG refers to Kellogg, Lander, Moffitt, and Gollehon (2000). Parameters used in equations for all livestock types listed come from Kellogg, Moffitt, and Gollehon (forthcoming).
AU = animal unit.
Source: USDA, Economic Research Service.

Appendix Table A2: Livestock types

Confined livestock types	Confined or pastured livestock types	Specialty livestock types
• Fattened cattle	• Horses and ponies	• Bison
• Veal calves	• Mules, burros, and donkeys	• Deer
• Milk cows	• Sheep	• Elk
• Breeding hogs	• Beef calves	• Llama
• Hogs for slaughter – farrow to wean	• Beef heifers for replacement herds	• Mink
• Hogs for slaughter – farrow to finish	• Beef breeding herds (cows and bulls)	• Rabbits
• Hogs for slaughter – finish only	• Beef stockers and grass fed beef	• Emu
• Hogs for slaughter – farrow to feeder	• Dairy calves	• Geese
• Hogs for slaughter – nursery	• Dairy heifers for replacement herds	• Ostriches
• Breeding turkeys	• Dairy stockers and grass fed animals marketed as beef	• Pheasants
• Slaughter turkeys	• Goats	• Pigeons
• Chicken layers		• Quail
• Chicken broilers		
• Chicken pullets		
• Ducks		

Source: USDA, Economic Research Service.

Appendix B: Calculating Number of Head and Animal Units for Cattle Types

As noted in appendix A, some equations for estimating the number of animals or animal units are not explicitly stated in KMG. While we attempt to replicate KMG, without knowing the precise equations, we may diverge from the KMG methodology. Hence, we state these methods here.

Fattened cattle

The equations for fattened cattle in KLMG are based on sales data, which were the only information collected on fattened cattle prior to the 2002 Census of Agriculture. As KMG note, end-of-year inventory for fattened cattle is also collected after that year, thus we use equations A1-A3 to estimate the number of fattened cattle on a farm. We use the parameters for cycles per year and number of animals per animal unit listed in KM.

(B1) If $Number\ of\ cattle\ on\ feed > 0$ and $Number\ of\ cattle\ shipped\ to\ slaughter > 0$

Then

$$Fattened\ cattle = \frac{Number\ of\ cattle\ on\ feed}{2.5} + \left(\frac{Number\ of\ cattle\ shipped\ to\ slaughter}{2.5} \times \frac{1.5}{2.5}\right)$$

And

$$Fattened\ cattle\ AU = \frac{Fattened\ cattle}{1.02}$$

(B2) If $Number\ of\ cattle\ on\ feed = 0$ and $Number\ of\ cattle\ shipped\ to\ slaughter > 0$

Then $Fattened\ cattle = \left(\frac{Number\ of\ cattle\ shipped\ to\ slaughter}{2.5}\right)$

And

$$Fattened\ cattle\ AU = \frac{Fattened\ cattle}{1.02}$$

(B3) If $Number\ of\ cattle\ on\ feed > 0$ and $Number\ of\ cattle\ shipped\ to\ slaughter = 0$

Then $Fattened\ cattle = \left(\frac{Number\ of\ cattle\ on\ feed}{2}\right) \times \frac{1}{2.5}$

And

$$Fattened\ cattle\ AU = \frac{Fattened\ cattle}{1.02}$$

Veal calves

The Census of Agriculture does not collect information on the number of veal calves at an operation, so we follow KMG and derive this number from sales of cattle weighing less than 500 lb. To do this, we first find farms without any dairy or beef cattle in inventory but with sales of cattle less than 500 lb. We calculate the potential number of veal AUs these sales would represent according to the following equation:

(B4) $$Potential\ Veal\ AUs = (Number\ of\ cattle\ less\ than\ 500\ lb\ \ sold) \times \frac{3.5}{12} \times \frac{1}{4.4}$$

The ratio $\frac{3.5}{12}$ represents the amount of the year that the veal calves are on the farm, and the 4.4 refers to the number of veal calves per animal unit. These parameters come from KMG.

We next calculate the total amount of pastureland on the farm by summing the acres of permanent pasture and rangeland, the acres of woodland pastured, and the cropland acres used only for pasture or grazing. If there were more than 12 potential veal AUs and the ratio of the potential veal AUs to the pastureland acres was greater than 8, then the number of veal AUs was set equal to the potential veal AUs (as in equation B4). Otherwise the number of veal AUs was set to zero.

Cattle other than dairy cows and fattened cattle

To calculate the number of the following types of cattle, we modify methods from KLMG:

- Beef calves
- Beef heifers for replacement herds
- Beef breeding herds (cows and bulls)
- Beef stockers and grass fed beef
- Dairy calves
- Dairy heifers for replacement herds
- Dairy stockers and grass fed animals marketed as beef

To calculate the number of these types of cattle, KLMG used information from a Census question on the number of bulls and steer at a farm. Starting in 2002, this information was no longer collected. The updated KMG provides some information but not complete detail as to what methods are followed instead to calculate these types of cattle. For clarity, we state our methods explicitly.

Pastured beef and dairy

For farms with beef cows but no dairy cows in inventory:

(B5) $$Bulls = \min\{(0.05 \times Beef\ cow\ inventory), \max[0, (Other\ cattle\ inventory - Fattened\ cattle)]\}$$

(B6) $$Beef\ cow\ breeding\ herd\ head = Beef\ cow\ inventory + Bulls$$

(B7) $Beef\ cow\ breeding\ herd\ AU = Beef\ cow\ breeding\ herd\ head$

(B8) $Expected\ beef\ calves = \min\{(beef\ cow\ inventory\ \times 0.82),$

$\max[0, (Other\ cattle\ inventory - Fattened\ cattle - Bulls)]\}$

Where 0.82 is the calving rate from KMG.

(B9) If $(Expected\ beef\ calves \leq Number\ of\ cattle\ less\ than\ 500\ lb\ sold)$ then

$Purchased\ and\ sold\ beef\ calves$

$= (\ Number\ of\ cattle\ less\ than\ 500\ lb\ sold) - \ (Expected\ beef\ calves)$

(B10) If $(Expected\ beef\ calves > Number\ of\ cattle\ less\ than\ 500\ lb\ sold)$ or

$(Number\ of\ cattle\ less\ than\ 500\ lb\ sold = 0)$ then

$Purchased\ and\ sold\ beef\ calves = 0$

(B11) $Beef\ calves\ head =$

$$\left[\left(Expected\ beef\ calves \times \frac{5}{12}\right) + \left(Purchased\ and\ sold\ beef\ calves \times \frac{2.5}{12}\right)\right]$$

(B12) $Beef\ calves\ AU = \frac{Beef\ calves\ head}{4}$

(B13) $Beef\ replacement\ herd\ heifers = \min\{(0.15 \times beef\ cow\ inventory),$

$\max[0, (Other\ cattle\ inventory - Expected\ beef\ calves - Fattened\ cattle$

$-Bulls)]\}$

Where 0.15 is the replacement rate for beef cows from KMG.

(B14) $Beef\ replacement\ herd\ heifer\ head = Beef\ replacement\ herd\ heifers\ \times \frac{5}{12}$

(B15) $Beef\ replacement\ herd\ heifer\ AU = \frac{(Beef\ replacement\ herd\ heifers\ head)}{1.14}$

(B16) $Beef\ stockers\ sold =$

$\max\{0, [Cattle\ more\ than\ 500\ lb\ sold - Fattened\ cattle\ sold]\}]\}$

(B17) $Beef\ stockers\ inventory =$

$$\max\{0, [Other\ cattle\ inventory - Beef\ replacement\ herd\ heifers\ head$$
$$-Bulls - Expected\ beef\ calves\ - Fatted\ cattle]\}$$

(B18) $Beef\ stockers\ head = \frac{Beef\ stockers\ inventory}{2} + \frac{Beef\ stockers\ sold}{4}$

(B19) $Beef\ stockers\ AU = \frac{Beef\ stockers\ head}{1.73}$

For farms with dairy cows but no beef cattle in inventory:

(B20) $Expected\ dairy\ calves = \min\{(dairy\ cow\ inventory\ \times 0.65),$

$$\max[0, (other\ cattle\ inventory - fattened\ cattle)]$$

Where 0.65 is the calving rate from KMG.

(B21) If $(Expected\ dairy\ calves \leq Number\ of\ cattle\ less\ than\ 500\ lb\ sold)$ then

$$Purchased\ and\ sold\ dairy\ calves = (\ Number\ of\ cattle\ less\ than\ 500\ lb\ sold) -$$
$$(Expected\ dairy\ calves)$$

(B22) If $(Expected\ dairy\ calves > Number\ of\ cattle\ less\ than\ 500\ lb\ sold)$ or

$(Number\ of\ cattle\ less\ than\ 500\ lb\ sold = 0)$ then

$$Purchased\ and\ sold\ dairy\ calves = 0$$

(B23) $Dairy\ calves\ head =$

$$\left[\left(expected\ dairy\ calves \times \frac{5}{12}\right) + \left(purchased\ and\ sold\ dairy\ calves \times \frac{2.5}{12}\right)\right]$$

(B24) $Dairy\ calves\ AU = \frac{Dairy\ calves\ head}{4}$

(B25) $Dairy\ replacement\ herd\ heifers =$

$$\min\{(0.2 \times Dairy\ cow\ inventory),$$
$$\max[0, (Other\ cattle\ inventory - Expected\ dairy\ calves$$
$$-Fattened\ cattle)]\}$$

Where 0.2 is the replacement rate for dairy cows from KMG.

(B26) $$Dairy\ replacement\ herd\ heifers\ head = \left(Dairy\ replacement\ herd\ heifers\ \times \frac{5}{12}\right)$$

(B27) $$Dairy\ replacement\ herd\ heifers\ AU = \frac{(Dairy\ replacement\ herd\ heifers\ head)}{1.04}$$

(B28) $$Dairy\ stockers\ sold = \max\{0,[(Cattle\ more\ than\ 500\ lb\ sold) - (Fattened\ cattle\ sold)]\}$$

(B29) $$Dairy\ stockers\ inventory = \max[0, (Other\ cattle\ inventory - Expected\ dairy\ calves - Dairy\ heifer\ head\ - Fattened\ cattle)]$$

(B30) $$Dairy\ stockers\ head = \frac{Dairy\ stocker\ inventory}{2} + \frac{Dairy\ stockers\ sold}{4}$$

(B31) $$Dairy\ stockers\ AU = \frac{Dairy\ stockers\ head}{1.73}$$

For farms with both dairy cows and beef cattle in inventory:

(B32) $$Bulls = \min\{(0.05 \times Beef\ cow\ inventory), \max[0, (Other\ cattle\ inventory - Fattened\ cattle)]\}$$

(B33) $$Beef\ cow\ breeding\ herd\ head = beef\ cow\ inventory + bulls$$

(B34) $$Beef\ cow\ breeding\ herd\ AU = Beef\ cow\ breeding\ herd$$

(B35) $$Expected\ dairy\ calves = \min\{(Dairy\ cow\ inventory\ \times 0.65), \max[0, (Other\ cattle\ inventory - Bulls - Fattened\ cattle)]\}$$

(B36) $\mathit{Dairy\ calves\ head} =$

$$\left[\left(\mathit{Expected\ dairy\ calves} \times \frac{5}{12}\right) + \left(\mathit{Purchased\ and\ sold\ dairy\ calves} \times \frac{2.5}{12}\right)\right]$$

(B37) $\mathit{Dairy\ calves\ AU} = \frac{\mathit{Dairy\ calves\ head}}{4}$

(B38) $\mathit{Expected\ beef\ calves} =$

$$\min\{(\mathit{Beef\ cow\ inventory}\ \times 0.82), \max[0, (\mathit{Other\ cattle\ inventory}$$
$$-\mathit{Fattened\ cattle} - \mathit{Bulls} - \mathit{Expected\ dairy\ calves})]\}$$

(B39) If $[(\mathit{Expected\ beef\ calves} + \mathit{expected\ dairy\ calves}) \leq$

$\mathit{Number\ of\ cattle\ less\ than}\ 500\ \mathit{lb\ sold}]$ then

$\mathit{Purchased\ and\ sold\ beef\ calves}$

$= (\ \mathit{Number\ of\ cattle\ less\ than}\ 500\ \mathit{lb\ sold})$

$-\ (\mathit{Expected\ beef\ calves}) - (\mathit{Expected\ dairy\ calves})$

(B40) If $[(\mathit{Expected\ beef\ calves} + \mathit{Expected\ dairy\ calves}) >$

$\mathit{Number\ of\ cattle\ less\ than}\ 500\ \mathit{lb\ sold}]$ or

$(\mathit{Number\ of\ cattle\ less\ than}\ 500\ \mathit{lb\ sold} = 0)$ then

$\mathit{Purchased\ and\ sold\ beef\ calves} = 0$

(B41) $\mathit{Beef\ calves\ head} =$

$$\left[\left(\mathit{expected\ beef\ calves} \times \frac{5}{12}\right) + \left(\mathit{purchased\ and\ sold\ beef\ calves} \times \frac{2.5}{12}\right)\right]$$

(B42) $\mathit{Beef\ calves\ AU} = \frac{\mathit{Beef\ calves\ head}}{4}$

(B43) $\mathit{Dairy\ replacement\ herd\ heifer\ inventory} =$

$$\min\{(0.2 \times \mathit{Dairy\ cow\ inventory}), \max[0, (\mathit{Other\ cattle\ inventory}$$
$$-\mathit{Fattened\ cattle} - \mathit{Bulls} - \mathit{Expected\ dairy\ calves}$$
$$-\mathit{Expected\ beef\ calves})]\}$$

(B44) $$Dairy\ replacement\ herd\ heifers\ head = \left(Dairy\ replacement\ herd\ heifers\ \times \frac{5}{12}\right)$$

(B45) $$Dairy\ replacement\ herd\ heifers\ AU = \frac{(Dairy\ replacement\ herd\ heifers\ head)}{1.04}$$

(B46) $$Beef\ replacement\ herd\ heifer\ inventory = \min\{(0.15\ \times beef\ cow\ inventory), max[0, (Other\ cattle\ inventory - Fattened\ cattle - Bulls - Dairy\ calves - Beef\ calves - Dairy\ replacement\ herd\ heifer\ inventory)]\}$$

(B47) $$Beef\ replacement\ herd\ heifer\ head = Beef\ replacement\ herd\ heifer\ inventory\ \times \frac{5}{12}$$

(B48) $$Beef\ replacement\ herd\ heifer\ AU = \frac{(Beef\ replacement\ herd\ heifers\ head)}{1.14}$$

(B49) $$Beef\ stockers\ sold = \max\{0, [(Cattle\ more\ than\ 500\ lb\ sold) - (fattened\ cattle\ sold)]\}$$

(B50) $$Beef\ stockers\ inventory = \max\{0, [Other\ cattle\ inventory - Beef\ replacement\ herd\ heifers - Bulls - Expected\ beef\ calves - Expected\ dairy\ calves - Dairy\ replacement\ herd\ heifers - Fattened\ cattle]\}$$

(B51) $$Beef\ stockers\ head = \frac{Beef\ stockers\ inventory}{2} + \frac{Beef\ stockers\ sold}{4}$$

(B52) $$Beef\ stockers\ AU = \frac{Beef\ stockers\ head}{1.73}$$

(B53) $Dairy\ stockers\ sold =$

$$\max\{0, [Cattle\ more\ than\ 500\ lb\ sold - \ Fattened\ cattle\ sold$$
$$- Beef\ stockers\ sold]\}$$

(B54) $Dairy\ stockers\ inventory =$

$$\max\{0, [Other\ cattle\ inventoryOther\ cattle\ inventory$$
$$- Beef\ replacement\ herd\ heifers - \ Bulls$$
$$- Expected\ beef\ calves - Expected\ dairy\ calves$$
$$- Dairy\ replacement\ herd\ heifers$$
$$- Fattened\ cattle - Beef\ stocker\ inventory]\}$$

(B55) $Dairy\ stockers\ head = \frac{Dairy\ stocker\ inventory}{2} + \frac{Dairy\ stockers\ sold}{4}$

(B56) $Dairy\ stockers\ AU = \frac{Dairy\ stockers\ head}{1.73}$

For farms with no beef or milk cows but with sales of cattle less than 500 lb but that are not veal farms:

(B57) $Beef\ calves\ head = Sales\ of\ cattle\ less\ than\ 500\ lb \times \frac{3.5}{12}$

And

$$Beef\ calves\ AU = \frac{Beef\ calves\ head}{4}$$

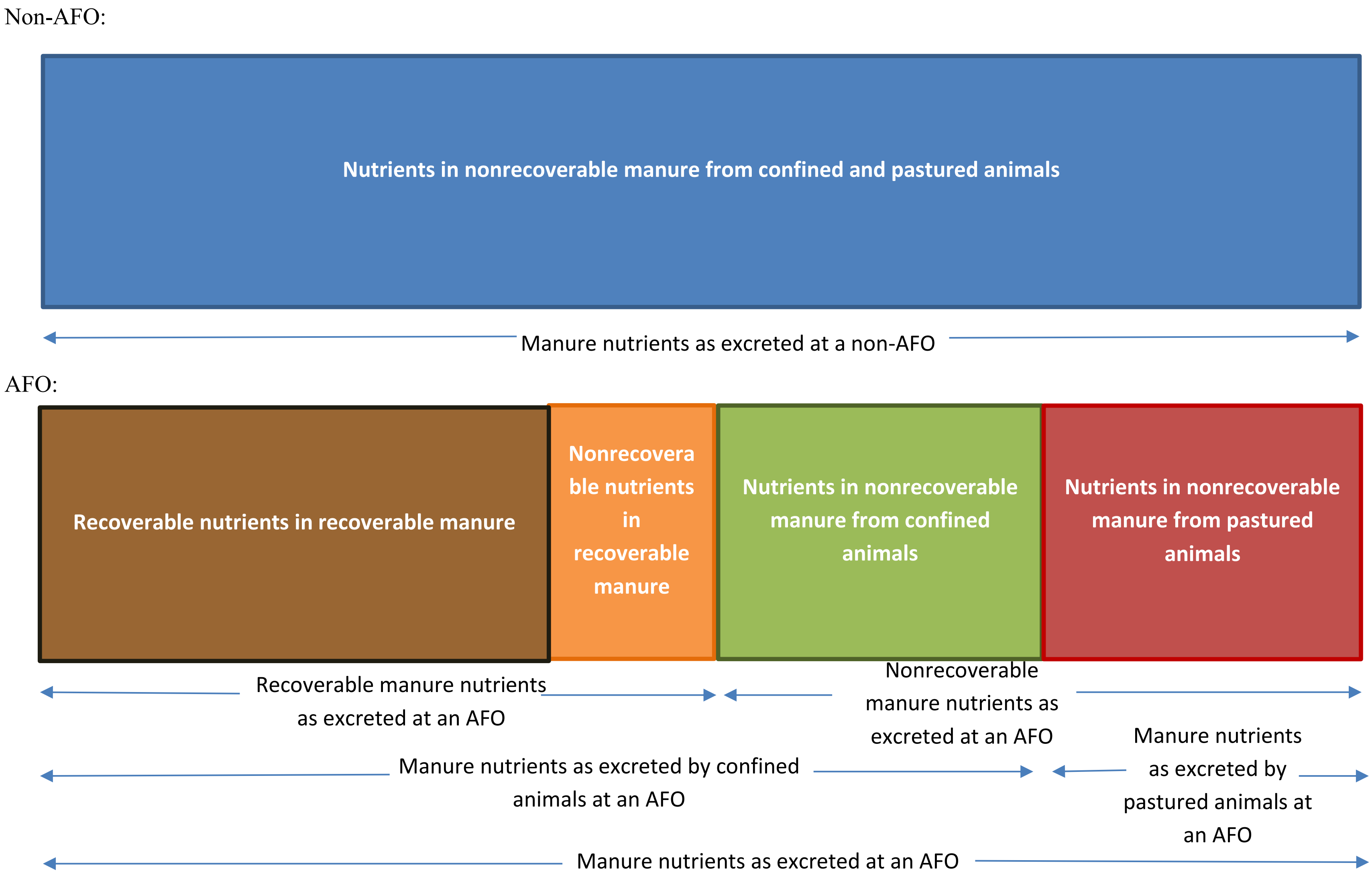
Appendix C: Estimating Manure Nutrients Generated

We calculate the amount of manure nutrients generated by animals and divide these amounts according to whether they can be recovered for later use onfarm or off-farm. This first involves characterizing which farms are predicted to be animal feeding operations (AFOs), as AFOs are the only types of livestock farms expected to have manure nutrients that can be recovered. Not all manure nutrients excreted at AFOs can be recovered. A portion of manure as excreted cannot be collected for later use, due to losses in handling and collection. Additionally, a portion of the nutrients in the recovered manure will not be available for later use, due to losses during collection, transfer, storage, and treatment. For nitrogen, this includes volatization.

We characterize nutrients according to the following categories (see appendix figure C1):

- Nonrecoverable manure nutrients at non-AFOs
    - This is comprised of all manure nutrients excreted by animals at non-AFOs.
- Recoverable manure nutrients at AFOs
    - These are the recoverable nutrients in the recoverable manure excreted from confined animals at AFOs.
- Nonrecoverable manure nutrients at AFOs
    - This includes the following:
        - Manure nutrients in nonrecoverable manure as excreted by both confined and pastured animals at AFOs
        - Nonrecoverable manure nutrients in the recoverable portion of manure.

Appendix Figure C1: Characterization of manure nutrients at animal feeding operations (AFOs) and non-AFOs



Source: USDA, Economic Research Service.

Characterizing animal feeding operations

In order to (in part) characterize operations as AFOs or not, for each farm we first estimate the dry weight of manure as excreted (DW) by confined animal types, using the following equation:

(C1) $DW = \sum_j [(Number\ of\ AUs)_j \times (Tons\ of\ manure\ per\ AU\ per\ year\ in\ oven - dry\ weight)_j]$

Parameters for tons of manure per AU per year are livestock-type-specific and can be found in KMG.

We next calculate the hauling weight from the dry weight of manure. Following KMG, we estimate the quantity of manure at hauling weight as two times the oven dry weight for all livestock types except poultry. For chicken broilers and ducks, the hauling weight is 1.3 times the dry weight, and for turkeys it is 1.5 times the dry weight.

For later estimates of manure shipping costs we also calculate the dry weight of manure for poultry (DW^B) versus other livestock types (DW^C).

We next characterize which operations are AFOs according to the number of confined AUs and the hauling weight of manure. Following KMG we assume that only operations with at least one of the following are AFOs:

1. More than 12 AUs of confined livestock types, including the portion of pastured livestock that were assumed to be confined.
2. More than 40 tons of manure at hauling weight produced by confined livestock AU, again including the manure from the portion of pastured livestock that were assumed to be confined.

Estimating nonrecoverable manure nutrients at non-AFOs

All manure nutrients excreted by animals at non-AFOs are assumed to be nonrecoverable, due to likely manure handling methods. Manure nutrients at non-AFOs are a function of the number of animals (either confined or pastured), type of animals, and a manure production factor which varies by type of animal and confinement (for those animal types that could be either confined or pastured). The parameters for the tons of wet weight manure per AU per year and the pounds of nutrient per ton of wet weight are from KMG and differ by animal type and confinement:

(C2) $$Nonrecoverable\ manure\ nutrients\ at\ non - AFOs = \sum_k [(Number\ of\ AUs\ )_k \times (Tons\ of\ wet\ weight\ manure\ per\ AU\ per\ year)_k \times (Pounds\ of\ nutrient\ per\ ton\ of\ wet\ weight)_k]$$

Note that k indexes all 36 types of confined and pastured animals; this is the total of manure nutrients excreted by both pastured and confined animals at a non-AFO.

Estimating recoverable manure nutrients at AFOs

The process of estimating recoverable manure nutrient at AFOs involves several steps.
The tons of wet weight of manure as excreted for confined animals at AFOs (WW) is calculated as:

(C3) $$Tons\ of\ wet\ weight\ manure =$$
$$\sum_j [(Number\ of\ AUs\ )_j \times (Tons\ of\ wet\ weight\ manure\ per\ AU\ per\ year)_j]$$

WW is later used to estimate shipping costs (see Appendix G). Note that j indexes just confined animal types.

Next we estimate the amount of manure that is recoverable and not lost in transport, handling, or storage, using additional parameters to estimate the amount of excreted manure that can be recovered (in tons):

(C4) $$Wet\ weight\ of\ recoverable\ manure\ (tons) =$$
$$\sum_j [(Wet\ weight\ of\ manure\ as\ excreted\ )_j \times (Manure\ recoverability\ factor)_j]$$

We then multiply by parameters for the pounds of nutrient per ton of wet weight to estimate the amount of nutrients in the recovered excreted manure (in pounds). Manure recoverability factors vary according to livestock type, region, and size class. Additionally, these vary according to the assumed degree of nutrient management plan adoption. As we are examining nutrient reduction after nutrient management plans are adopted, we use the manure recoverability factors for 2012.

(C5) $$Nutrients\ recoverable\ manure\ (pounds) =$$
$$\sum_j [(Wet\ weight\ of\ recoverable\ manure)_j$$
$$\times (Pounds\ of\ nutrient\ per\ ton\ of\ wet\ weight)_j]$$

Finally, we multiple by parameters for the amount of *recovered* elemental nitrogen in the *recovered* excreted manure (N_M, in pounds). The parameters for the proportion of nutrients retained in recoverable manure are found in KMG and vary according to animal type. The proportion of nutrients not retained in recoverable manure is lost in transportation and to the atmosphere:

(C6) $$N_M = \sum_j [(Nutrients\ in\ recoverable\ manure)_j \times$$
$$(Proportion\ of\ nutrients\ retained\ in\ recoverable\ manure)_j]$$

Estimating nonrecoverable manure nutrients at AFOs

The nonrecoverable manure nutrients at AFOs are comprised of two parts: (1) the manure nutrients in nonrecoverable manure as excreted by confined and pastured animals at AFOs, and (2) the nonrecoverable manure nutrients in the recoverable portion of manure.

To estimate the manure nutrients in the nonrecoverable manure at AFOs, we first estimate the wet weight of the nonrecoverable manure from confined animals at AFOs:

(C7) $$Wet\ weight\ of\ nonrecoverable\ manure\ from\ confined\ animals\ (tons) = \sum_j [(Wet\ weight\ of\ manure\ as\ excreted\ )_j \times (1 - Manure\ recoverability\ factor)_j]$$

This is then multiplied by the pounds of nutrient per ton of wet weight to get the amount of nonrecoverable manure nutrients

(C8) $$Nutrients\ in\ nonrecoverable\ manure\ from\ confined\ animals\ (pounds) = \sum_j [(Wet\ weight\ of\ nonrecoverable\ manure\ (tons))_j \times (Pounds\ of\ nutrient\ per\ ton\ of\ wet\ weight)_j]$$

Finally, we estimate the amount of nutrients in nonrecoverable manure from *pastured* animals at AFOs. First, we estimate the amount of wet weight manure excreted by pastured animals at AFOs:

(C9) $$Wet\ weight\ of\ nonrecoverable\ manure\ from\ pastured\ animals\ (tons) = \sum_i [(Number\ of\ AUs\ )_i \times (Tons\ of\ wet\ weight\ manure\ per\ AU\ per\ year)_i]$$

Note that i indexes just pastured animal types.

We then multiply by parameters for the pounds of nutrient per ton of wet weight to estimate the amount of nutrients in the nonrecoverable manure excreted by pastured animals at AFOS:

(C10) $$Nutrients\ in\ nonrecoverable\ manure\ from\ pastured\ animals (pounds) = \sum_i [(Wet\ weight\ of\ nonrecoverable\ manure)_i \times (Pounds\ of\ nutrient\ per\ ton\ of\ wet\ weight)_i]$$

The nutrients in nonrecoverable manure at AFOs are the sum of the values in (C8) and (C10).

To estimate the nonrecoverable manure nutrients in the recoverable portion of manure, we first use the amount of nutrients in recoverable manure at AFOs estimated in (C5). We then multiply by one minus the proportion of nutrients retained in recoverable manure:

(C11) $Nonrecoverable\ manure\ nutrients\ in\ recoverable\ manure =$

$$\sum_j [(Nutrients\ in\ recoverable\ manure)_j \times (1 - Proportion\ of\ nutrients\ retained\ in\ recoverable\ manure)_j]$$

The total amount of nonrecoverable manure nutrients at AFOs is the sum of the results of (C8), (C10), and (C11).

Appendix D: Calculation of Nutrient Assimilative Capacity of Crops and Pastureland

We calculate the amount of nutrients that can be assimilated by farms' harvested cropland, cropland used as pasture, and permanent pastureland, again following KMG.

Harvested cropland

We estimate the amount of nitrogen and phosphorus that can be assimilated by harvested crops by using the Census of Agriculture stated yield for a specific crop, a nutrient uptake and removal coefficient, and an assumption on the fertilizer or manure application-removal ratio.

The amount of nutrient (nitrogen or phosphorus) used on the crops (N_U^{Cr}) at an individual operation is estimated according to the following equation:

(D1) $$N_U^{Cr} = \sum_k [(Yield)_k \times (Nutrient\ per\ yield\ unit)_k]$$

Here, k indexes the crop type at the individual operation. The pounds of nutrient per yield unit come from KMG, who attribute them to the National Uptake and Removal Database constructed and maintained by the International Plant Nutrition Institute.

Appendix table D1 lists the 21 crops for which we estimate the amount of nitrogen assimilative capacity on harvested cropland.

Appendix Table D1: Crops for which nutrient assimilative capacity is estimated

• Corn for grain	• Rice
• Corn for silage	• Peanuts for nuts
• Sorghum for grain	• Sugar beets for sugar
• Sorghum for silage	• Tobacco
• Cotton (lint and seed)	• Soybeans
• Barley	• Alfalfa hay
• Winter wheat	• Small grain hay
• Durum wheat	• Other tame hay
• Other spring wheat	• Wild hay, including sorghum hay
• Oats	• Grass silage
• Rye for grain	

Source: USDA, Economic Research Service.

Cropland used as pasture and permanent pasture

Since no crops are harvested on cropland used as pasture and pastureland, we cannot calculate nutrient uptake from this land type. We therefore follow KMG first and assume that there will be different assimilative capacities for cropland used as pasture and permanent pastureland. However, the Census does not report permanent pasture, instead providing "permanent pasture plus rangeland" combined. In order to allocate acreage in the Census category to permanent pasture, we follow KMG and use the National

Resources Inventory (NRI). The NRI contains separate information on permanent pastureland and rangeland. NRCS provided us with a dataset providing the acreages in a county in permanent pastureland and rangeland. We calculate the percentage of county-level permanent pastureland plus rangeland that is in permanent pastureland; we then apply this county-level percentage to individual farms to estimate the amount of permanent pastureland on each farm.

After calculating the amounts of cropland used as pasture and permanent pastureland, we find the assimilative capacity on these types of fields by multiplying acreage by a per-acre nutrient parameter. Following KMG, we assume that 75 lbs of nitrogen can be applied per acre of cropland used as pasture and that 30 lbs of nitrogen can be applied per acre of permanent pastureland. For phosphorus, these are 28 lbs for cropland used as pasture and 11 lbs for permanent pastureland.

(D2) $$N_U^{P1} = (Acres\ of\ cropland\ used\ as\ pasture) \times (Nutrients\ per\ acre\ of\ cropland\ used\ as\ pasture)$$

(D3) $$N_U^{P2} = (Acres\ of\ permanent\ pastureland) \times (Nutrients\ per\ acre\ of permanent\ pastureland)$$

The total assimilative capacity on the farms pastured acreage is the sum of these:

(D4) $$N_U^{P} = N_U^{P1} + N_U^{P2}$$

Total farm-level nutrient assimilative capacity on crops and pastureland

The total farm-level nutrient assimilative capacity represents the amount of nutrients that will be used by crops and pasture:

(D5) $$N_{U=}N_U^{Cr} + N_U^{P}$$

Note that producers apply more nutrients than the assimilative capacity, with the expectation that a portion of the nutrients applied will be lost to run-off or the atmosphere. We describe application in appendix E.

Appendix E: Calculation of Amount of Nutrients Applied

The nutrient assimilative capacity represents the amount that crops and pasture use; however, this differs from the amount of nutrients that can be applied in an agronomic fashion. We make two assumptions regarding the amount of nutrients applied in an agronomic fashion. First, producers will only apply nutrients to certain crops. Second, we assume that crops will only use a portion of the nutrients applied, as a portion of nutrients are assumed to be lost before they can be used by the crop. Hence, we assume an application-removal ratio greater than one multiplied by the amount of nutrients used will provide an estimate of the amount needed for recorded yields on the crops. For nitrogen, we use an application-removal ratio of 1.4, which represents a 71-percent assimilation rate; this means that 71 percent of the elemental nitrogen applied will be used by crops. KMG note that this ratio is "an acceptable rate of application when nitrogen losses are not well controlled by conservation practices" (p. 19). The amount of elemental nitrogen needed for recorded yields (N_A) is therefore 1.4 times the amount of nitrogen used (N_U):

(E1) $$N_A = 1.4N_U$$

For phosphorus, we use an application-removal rate of 1.05.

Nutrients can be applied either as fertilizer or manure. To estimate the amount of applied manure versus fertilizer, we do the following. Let N_M refer to the *recovered* manure nutrients, and N_F is the amount of nutrients in fertilizer:

1. If a farmer produces no recoverable manure ($N_M = 0$), then s/he applies nitrogen in fertilizer at least equal to 15 percent of the amount of nitrogen needed for agricultural fields ($N_F \geq .15N_A$).
2. If $N_M > N_A$, then s/he applies no commercial fertilizer ($N_F = 0$). This farmer applies N_M.
3. If a farmer produces recoverable manure nitrogen in an amount less than what is needed for agricultural fields ($N_M < N_A$), then s/he applies fertilizer to make up the difference between N_M and N_A such that $N_F = N_A - N_M$.

Note that by assumption, the only operations that overapply nitrogen are farms with recoverable manure nitrogen.

Appendix F: Detail of Model

The farmer will generate nutrient credits for sale if the value of doing so (V) is positive ($V > 0$). V is the difference between the amount accrued from the sale of the credits and the costs of meeting the baseline and generating the credits:

(F1) $V = P_X X - C_B - C_X$

Where P_X is the price per credit, X is the number of credits generated, C_B is the cost of meeting the baseline, and C_X is the cost of generating credits.

Allow $\overline{N}$ and N to be the total amounts of the nutrient applied before and after a 15-percent reduction in nutrient application to cropland (respectively) such that $N = 0.85\overline{N}$. Allow $Y_k(\overline{N})$ to be the yields in commodity k on the farm raised with the amount of the nutrient ($\overline{N}$) used when applying at agronomic rates, and $Y_k(N)$ is yields raised with 85 percent of the agronomic rates. The change in yields due to the 15 percent reduction in nutrient application to cropland will be $Y_k(\overline{N}) - Y_k(N)$.

The sum of the amounts of the nutrient from fertilizer and manure applied ($\overline{N_F}$ and $\overline{N_M}$) equals the total amounts applied: $\overline{N_F} + \overline{N_M} = \overline{N}$. Likewise, the amounts applied after a 15-percent reduction in nutrient applications to cropland (N_F and N_M) sum to the total (N): $N_F + N_M = N$.

The cost of generating credits will be the cost of reduced yields net of the changes in the costs of fertilizer and manure transport:

(F2) $C_X = \sum_k \{P_k [Y_k(\overline{N}) - Y_k(N)]\} - P_F(\overline{N_F} - N_F) + P_M(\overline{N_M} - N_M)$

Where P_k is the unit price of crop commodity k. P_F is the purchase price per unit of fertilizer, and P_M is the price per unit to ship the nutrient in manure off-farm.

We assume that the producer does not increase the nutrient from any source to meet the 15-percent reduction, hence $N_F \leq \overline{N_F}$ and $N_M \leq \overline{N_M}$.

The value of the nutrient credit will therefore be:

(F3) $V = P_X X - C_B - \sum_k \{P_k [Y_k(\overline{N}) - Y_k(N)]\} + P_F(\overline{N_F} - N_F) - P_M(\overline{N_M} - N_M)$

The main point of this equation is that decreasing fertilizer use will increase the value of credits, while shipping manure off-farm will decrease the value.

Appendix G: Calculation of Amounts of Manure and Fertilizer Removed for Nutrient Trading

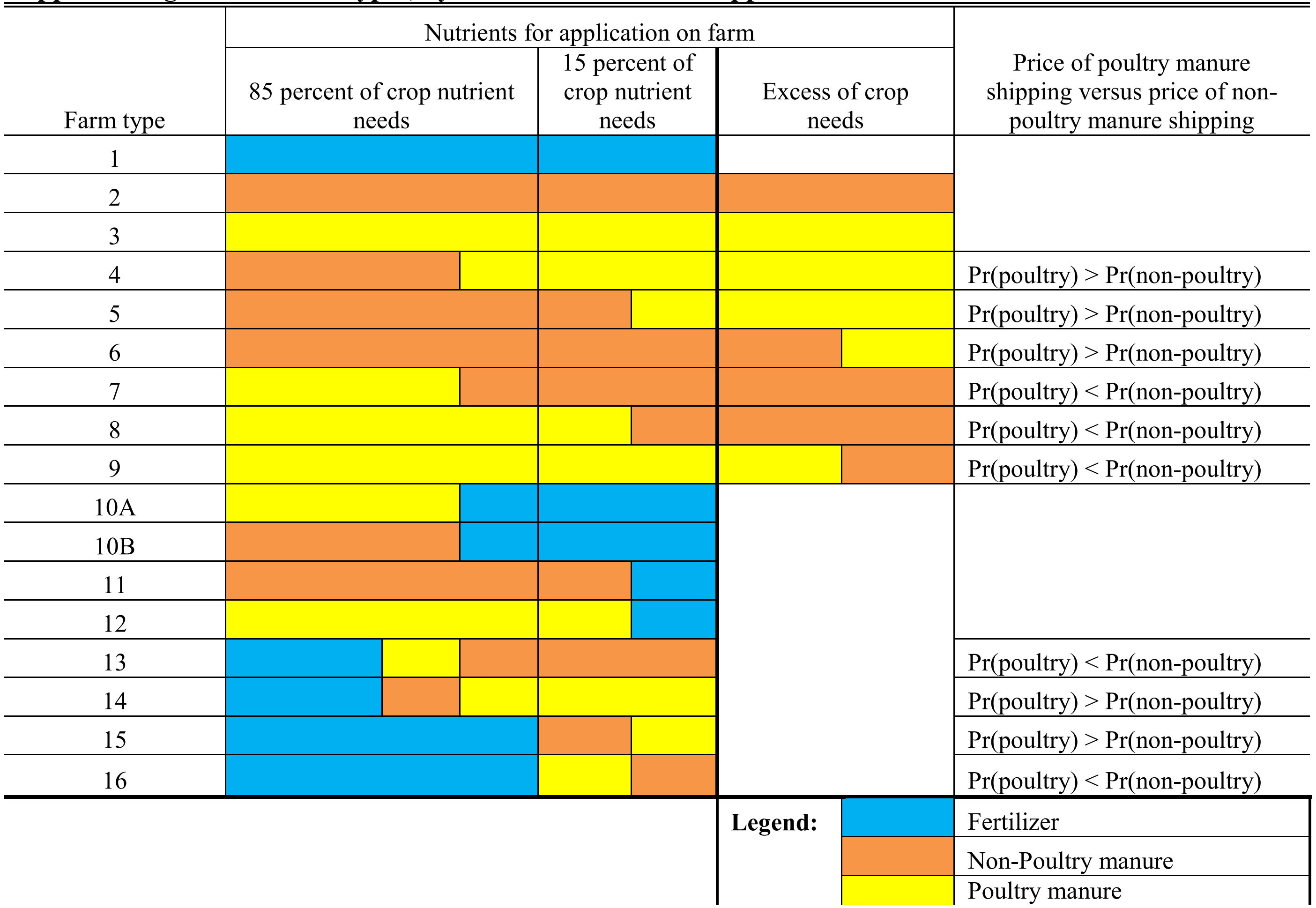
In the main text, we model a farmer's decision to participate in nutrient trading via a 15-percent reduction in nutrient application to cropland. To participate, a farmer must meet baseline criteria, including a nutrient management plan (NMP). To generate credits, the farmer must reduce nitrogen application by 15 percent after satisfying the NMP and applying at agronomic rates.

To meet the NMP, farmers that currently apply more nitrogen or phosphorus than needed ($N_M > N_A$) must first ship $N_M - N_A$ off-farm. Note that by assumption the only operations that over-apply nitrogen do so with manure. Hence, the only nitrogen or phosphorus reduced to meet the NMP will be in the form of manure. We allow different manure shipping costs for poultry litter, which is generally dry, and non-poultry manure, which is generally wet (Ribaudo et al., 2003). If an operation generates both poultry litter and non-poultry manure, it will reduce whichever is less expensive to ship first.

To implement a 15-percent reduction in nutrient applications to cropland, the operation must reduce nitrogen or phosphorus application by 15 percent from the amount needed for application at agronomic rates on crops ($0.15N_A^C$). What form this nitrogen takes (manure or fertilizer) will depend on the amounts applied as well as the relative costs of removing these types of nitrogen or phosphorus. We consider possible reduction in three sources of elemental nitrogen or phosphorus: that from fertilizer, that from poultry litter, and that from non-poultry manure. As reduction of fertilizer represents a cost-savings and reduction of manure represents additional costs, an operator will first reduce fertilizer use. If an operation generates both poultry litter and non-poultry manure, it will reduce whichever is less expensive to ship first.

We describe how 16 different farm types would satisfy the 15-percent reduction in nutrient applications to cropland (see appendix figure G1). These farm types differ depending on the amount of nitrogen or phosphorus applied in the form of fertilizer, poultry litter, and manure from non-poultry livestock, as well as the relative costs of reducing each of these.

Appendix Figure G1: Farm types, by fertilizer and manure application



Source: USDA, Economic Research Service.

To aid in comprehending these scenarios, we provide appendix table G1, which lists the variables used and provides descriptions of them.

Note that for all farm types, the recovered nitrogen or phosphorus in recoverable poultry litter plus that in recoverable non-poultry manure will add up to the total amount of recovered nitrogen or phosphorus:

(G1) $$N_M = N_M^B + N_M^C$$

Appendix Table G1: Variables used in nitrogen reduction scenarios

Variable	Description	Units
DW	Dry weight of manure as excreted	Tons
DW^B	Dry weight of manure as excreted – poultry	Tons
DW^C	Dry weight of manure as excreted – non-poultry livestock	Tons
WW	Wet weight of manure as excreted	Tons
WW^B	Wet weight of manure as excreted – poultry	Tons
WW^C	Wet weight of manure as excreted – non-poultry livestock	Tons
N_M	Recovered elemental nutrients in recovered manure	Pounds
N_M^B	Recovered elemental nutrients in recovered manure – poultry	Pounds
N_M^C	Recovered elemental nutrients in recovered manure – non-poultry livestock	Pounds
N_U	Elemental nutrients used on crops and pastureland	Pounds
N_A	Elemental nutrients applied to crops and pastureland	Pounds
N_A^{Cr}	Elemental nutrients applied to crops	Pounds
N_F	Elemental nutrients applied as fertilizer	Pounds
P_M^C	Price to remove a pound of elemental nutrients in non-poultry livestock manure	Dollars
P_M^B	Price to remove a pound of elemental nutrients in poultry litter	Dollars

Note: The nutrient is either nitrogen or phosphorus.
Source: USDA, Economic Research Service.

The 16 farm types are shown in appendix table G2, and the relative amount of manure and fertilizer that they reduce to meet the baseline NMP and to generate credits under the 15-percent reduction in nutrient applications to cropland are shown in appendix table G3.

Appendix Table G2: Types of farms according to relative amounts of manure and fertilizer on farm

Farm type	N_M	N_M^B	N_M^C	P_M^B vs. P_M^C	N_F
1	$N_M = 0$	$N_M^B = 0$	$N_M^C = 0$	NA	$N_F = N_A$
2	$N_M \geq N_A$	$N_M^B = N_M$	$N_M^C = 0$	NA	$N_F = 0$
3	$N_M \geq N_A$	$N_M^B = 0$	$N_M^C = N_M$	NA	$N_F = 0$
4	$N_M \geq N_A$	$N_M^B > 0$	$N_M^C > N_M - N_A > 0$ and $N_M^C - (N_M - N_A) \geq .15N_A^{Cr}$	$P_M^B > P_M^C$	$N_F = 0$
5	$N_M \geq N_A$	$N_M^B > 0$	$N_M^C > N_M - N_A > 0$ and $N_M^C - (N_M - N_A) < .15N_A^{Cr}$	$P_M^B > P_M^C$	$N_F = 0$
6	$N_M \geq N_A$	$N_M^B > 0$	$0 < N_M^C < N_M - N_A$	$P_M^B > P_M^C$	$N_F = 0$
7	$N_M \geq N_A$	$N_M^B > N_M - N_A > 0$ and $N_M^B - (N_M - N_A) \geq .15N_A^{Cr}$	$N_M^C > 0$	$P_M^B < P_M^C$	$N_F = 0$
8	$N_M \geq N_A$	$N_M^B > N_M - N_A > 0$ and $N_M^B - (N_M - N_A) < .15N_A^{Cr}$	$N_M^C > 0$	$P_M^B < P_M^C$	$N_F = 0$
9	$N_M \geq N_A$	$0 < N_M^B < N_M - N_A$	$N_M^C > 0$	$P_M^B < P_M^C$	$N_F = 0$
10	$N_M < 0.85N_A^{Cr}$	NA	NA	NA	$N_F = N_A - N_M$
11	$0.85N_A^{Cr} < N_M < N_A^{Cr}$	$N_M^B > 0$	$N_M^C = 0$	NA	$N_F = N_A - N_M$
12	$0.85N_A^{Cr} < N_M < N_A^{Cr}$	$N_M^B = 0$	$N_M^C > 0$	NA	$N_F = N_A - N_M$
13	$0.85N_A^{Cr} < N_M < N_A^{Cr}$	$N_M^B > .15N_A^{Cr} - N_F > 0$	$N_M^C > 0$	$P_M^B < P_M^C$	$N_F = N_A - N_M$
14	$0.85N_A^{Cr} < N_M < N_A^{Cr}$	$N_M^B > 0$	$N_M^C > .15N_A^{Cr} - N_F > 0$	$P_M^B > P_M^C$	$N_F = N_A - N_M$
15	$0.85N_A^{Cr} < N_M < N_A^{Cr}$	$N_M^B > 0$	$0 < N_M^C < .15N_A^{Cr} - N_F$	$P_M^B > P_M^C$	$N_F = N_A - N_M$
16	$0.85N_A^{Cr} < N_M < N_A^{Cr}$	$0 < N_M^B < .15N_A^{Cr} - N_F$	$N_M^C > 0$	$P_M^B < P_M^C$	$N_F = N_A - N_M$

NA = Not applicable.
Source: USDA, Economic Research Service.

Appendix Table G3: Amounts of manure and fertilizer reduced to meet baseline NMP and a 15-percent reduction in nutrient application to cropland

	To meet the baseline NMP		To meet 15-percent reduction in nutrient application		
Farm type	Amount of poultry litter exported	Amount of other livestock manure exported	Amount of fertilizer reduced	Amount of poultry litter reduced	Amount of other livestock manure reduced
1	0	0	$0.15N_A^{Cr}$	0	0
2	$N_M^B - N_A$	0	0	$0.15N_A^{Cr}$	0
3	0	$N_M^C - N_A$	0	0	$0.15N_A^{Cr}$
4	0	$N_M^C - N_A$	0	0	$0.15N_A^{Cr}$
5	0	$N_M^C - N_A$	0	$0.15N_A^{Cr} - [N_M^C - (N_M - N_A)]$	$N_M^C - (N_M - N_A)$
6	$(N_M - N_A) - N_M^C$	N_M^C	0	$0.15N_A^{Cr}$	0
7	$N_M^B - N_A$	0	0	$0.15N_A^{Cr}$	0
8	$N_M^C - N_A$	0	0	$N_M^B - (N_M - N_A)$	$0.15N_A^{Cr} - [N_M^B - (N_M - N_A)]$
9	N_M^B	$(N_M - N_A) - N_M^B$	0	0	$0.15N_A^{Cr}$
10	0	0	$0.15N_A^{Cr}$	0	0
11	0	0	N_F	$0.15N_A^{Cr} - N_F$	0
12	0	0	N_F	0	$0.15N_A^{Cr} - N_F$
13	0	0	N_F	$.15N_A^{Cr} - N_F$	0
14	0	0	N_F	0	$.15N_A^{Cr} - N_F$
15	0	0	N_F	$.15N_A^{Cr} - N_F - N_M^C$	N_M^C
16	0	0	N_F	N_M^B	$.15N_A^{Cr} - N_F - N_M^B$

NMP = nutrient management plan.
Source: USDA, Economic Research Service.

Appendix H: Model Parameters

Baseline requirements

Meeting the baseline requires satisfying the NMP and instituting other practices. We assume that a NMP requires application of nutrients at agronomic rates such that nutrient applications match the operation's assimilative capacity. We assume that the NMP includes a per-acre plan development cost as well as an additional cost of shipping manure off-farm for farms that produce excess nutrients. In the case of livestock producers that generate more manure nutrients than can be used on their crops, the cost of meeting the baseline will include the cost of shipping manure offsite. Shipping costs are described below.

Costs for other baseline practices arise from a World Resources Institute examination of best management practices used in the Chesapeake Bay. Information on these practices and this data gathering can be found in Ribaudo et al. (2014).

We calculate annualized costs for each requirement. Some requirements have both start-up and per-year maintenance costs, while others have just per-year maintenance costs. Pasture fencing, grass buffers, barnyard runoff controls, and mortality composting are all assumed to have both startup and maintenance costs. Annualized costs are calculated with the following formula:

(H1) $$Cost\ per\ year = NPV \times \frac{r(1+r)^T}{(1+r)^{(T+1)}-1}$$

Where r is the discount value, T is the time that the project lasts, and NPV is the net present value. The discount rate is assumed to be 7 percent, and the time horizon for all project is assumed to be 8 years. The net present value is calculated as:

(H2) $$NPV = \sum_{t=0}^{T} SC + C_t\left(\frac{1}{(1+r)^t}\right)$$

Where SC is the startup cost accrued in the first year, and C_t is the per-year maintenance cost.

The specific practices by type of farm are listed in appendix table H1. The annualized price for each practice is shown under different financial assistance share levels.

Appendix Table H1: Baseline costs other than implementation of NMP					
			Cost per unit per year		
			Financial assistance share		
Applied to…	Required for baseline	Unit	0	50	75
			--------- *2012 Dollars* --------		
Farms with cropland	Nutrient management plan (excluding costs of implementation)	Acres of cropland	29.9	14.95	7.48
	Cover crops	Acres of cropland	62.80	31.40	15.70
	Conservation tillage	Acres of cropland	22.34	11.17	5.59
	Grass buffers	Farm	58.38	29.19	14.60
Farms with livestock	Barnyard run-off control	Farm	772.30	386.15	193.07
	Animal waste management system	Farm	111.11	55.55	27.78
	Mortality composting	Farm	787.87	393.94	196.97
Farms with non-confined livestock	Fencing for animal exclusion	Farm	524.69	262.34	131.17
	Prescribed grazing	Acres of pastureland	43.01	21.51	10.75

Note: Farms can be in multiple categories. For example, a farm can have cropland as well as livestock, in which case all of the requirements for "farms with cropland" and "farms with livestock" must be met.
NMP = nutrient management plan.
Source: USDA, Economic Research Service.

Prices for crops

Prices for crop were obtained largely from the National Agricultural Statistics Service; values of corn silage, sorghum silage, and grass silage are calculated in relationship to the price of corn.

Appendix Table H2: Commodity prices used in simulation

Commodity	2012	2009	2007	Source and/or assumptions
	Price per unit (2012 dollars)			
Corn for grain (bu)	6.89	3.80	4.65	NASS (2009, 2011, 2014)
Corn for silage (ton)	50.69	27.95	34.22	Set at (27/3.67) the price of corn for grain; calculates the grain content of the corn silage; Snyder (2011).
Soybeans (bu)	14.40	10.26	11.18	NASS (2009, 2011, 2014)
Sorghum for grain (bu)	6.33	3.45	4.51	NASS (2009, 2011, 2014); NASS prices listed per cwt; conversion of cwt to bu assumes 56 lbs/bu.
Sorghum for silage (ton)	45.62	25.16	30.79	Set at 90 percent of corn silage price; Guyer and Duey (1974).
Cotton (lint and seed) (lb)	0.76	0.69	0.68	NASS (2009, 2011, 2014)
Barley (bu)	6.43	4.99	4.45	NASS (2009, 2011, 2014)
Winter wheat (bu)	7.55	5.04	6.79	NASS (2009, 2011, 2014)
Durum wheat (bu)	8.18	5.85	10.98	NASS (2009, 2011, 2014)
Other spring wheat (bu)	8.24	5.60	7.93	NASS (2009, 2011, 2014)
Oats (bu)	3.89	2.16	2.91	NASS (2009, 2011, 2014)
Rye for grain	7.67	5.28	5.55	NASS (2009, 2011, 2014)
Rice	15.10	15.41	14.17	NASS (2009, 2011, 2014)
Peanuts for nuts (lb)	0.301	0.23	0.23	NASS (2009, 2011, 2014)
Sugar beets for sugar (ton)	66.60	53.94	46.40	NASS (2009, 2011, 2014)
Tobacco	2.069	1.97	1.87	NASS (2009, 2011, 2014)
Alfalfa hay (ton)	210.00	120.93	152.81	NASS (2009, 2011, 2014)
Small grain hay (ton)	142.00	104.13	121.81	NASS (2009, 2011, 2014)
Other tame hay (ton)	142.00	104.13	121.81	NASS (2009, 2011, 2014)
Wild hay, including sorghum hay (ton)	142.00	104.13	121.81	NASS (2009, 2011, 2014)
Grass silage (ton)	44.12	24.33	29.78	Set at (22.85/26.25) the corn silage price. Staples (1995).

NASS = USDA, National Agricultural Statistics Service; bu = bushel; cwt = hundredweight.
Source: USDA, Economic Research Service.

Price of fertilizer

The amount of recoverable nitrogen in manure is calculated in pounds. For simplicity, we assume all nitrogen fertilizer is obtained via anhydrous ammonia, which is 82 percent nitrogen (Pennsylvania State University Agronomy Guide, 2011-2012). To get the amount of anhydrous ammonia fertilizer, we divide the pounds of nitrogen by 0.82. We also convert from pounds to tons by dividing by 2,000. P_{F_N} is the price per pound of elemental nitrogen in anhydrous fertilizer:

(H3) $$P_{F_N} = \frac{1}{0.82} \times Price\ per\ ton\ of\ anhydrous\ fertilizer \times \frac{1}{2000}$$

For phosphorus, we assume that all phosphorus fertilizer is obtained via super-phospate, which is 46 percent phosphorus. To calculate the amount of super-phospate fertilizer, we divide the pounds of phosphorus by 0.46. Super-phosphate (44-46 percent) sold for $665/ton in 2012 (USDA/ERS, 2012). We therefore convert from pounds to tons by dividing by 2,000. P_{F_P} is the price per pound of elemental phosphorus in fertilizer:

(H4) $$P_{F_P} = \frac{1}{0.46} \times Price\ per\ ton\ of\ super - phosphate\ (44 - 46\%) \times \frac{1}{2000}$$

Dropping the N- and P- sub-sub-scripts, the amount saved by reducing nitrogen fertilizer is therefore:

(H5) $$Cost\ of\ fertilizer\ change = \Delta N_F \times P_F$$

Where ΔN_F is the change in the respective nutrient fertilizer due to instituting a 15-percent reduction in nutrient application to cropland in pursuit of generating credits.

Appendix Table H3: Fertilizer prices, 2012		
Product	Price per ton of fertilizer (nominal)	Price per pound of elemental N or P (nominal)
	2012 dollars	
Anhydrous ammonia	$783	$0.48
Super-phosphate	$665	$0.72
	2009	
Anhydrous ammonia	850	$0.52
	2007	
Anhydrous ammonia	653.75	$0.40

Note: To calculate price per ton of N, anhydrous ammonia is assumed to be 82-percent nitrogen (Pennsylvania State University Agronomy Guide, 2011-2012). To calculate price per ton of P, super-phosphate is assumed to be 46 percent phosphorus (it is listed as between 44 and 46 percent). To convert from price per ton to price per pound, numbers are divided by 2,000.
N = nitrogen; p = phosphorus.
Source: USDA, Economic Research Service, 2012 price per ton data.

Manure shipping price

We allow different per unit shipping costs along two dimensions: First, whether the nutrients in the manure arise from poultry or other livestock types; second, the sub-watershed of the farm. We assume, following past research (Ribaudo et al., 2003), that poultry litter is dry while manure from other livestock types is wet. Ribaudo and coauthors (2003) estimate the manure hauling costs in the Chesapeake Bay watershed. For wet manure from lagoon and slurry systems, they report per ton base charges as well as per ton per mile hauling costs when shipping off-farm.

Appendix Table H4: Per-unit manure shipping prices		
Description	Base charge per ton	Per mile charge per ton
	2012 dollars	
Shipping price per ton of dry weight litter	$12.50	$0.14
Shipping price per ton of wet weight manure	$2.50	$0.38

Source: Ribaudo et al., 2003.

The distance shipped will depend on the sub-watershed within the Chesapeake Bay. There are 7 sub-watersheds within the Chesapeake Bay, characterized by their 6-digit hydrologic unit codes (HUC-6). Shipping distances vary by HUC-6 based on the availability of land for manure nutrient application. Ribaudo et al. estimate shipping distances by HUC-6, according to the willingness of crop farmers to accept manure. We use the values when farmers are willing to accept 30 and 50 percent of manure shipped.

Appendix Table H5: Average off-farm hauling distance, by willingness-to-accept manure and sub-basin in the Chesapeake Bay

		Percent willing to accept manure	
		30	50
6-digit Hydrologic Unit Code	**Sub-basin name**	**Miles**	
020501	Upper Susquehanna River	2.0	1.7
020502	West Branch Susquehanna River	2.4	2.0
020503	Lower Susquehanna River	13.2	4.4
020600	Upper Chesapeake Bay	28.5	16.7
020700	Potomac River	43.0	34.2
020801	Lower Chesapeake Bay	25.4	18.2
020802	James River	23.5	14.1

Source: Ribaudo et al., 2014. p. 41. http://www.ers.usda.gov/publications/err-economic-research-report/err166.aspx

In the base scenario, we use the distances for a 50-percent willingness to accept manure. We perform two sensitivity analyses. In the first, we use the distances for the 30-percent willingness-to-accept manure. In the second, we use the distances for the 50-percent willingness-to-accept, but halve them in the case of wet manure and double them in the case of dry manure.

In appendix G, we describe how we estimate the changes in nitrogen in poultry litter and non-poultry manure needed to participate in nutrient trading. For non-poultry manure, we estimate the change in (elemental) nitrogen or phosphorus in manure in pounds per ton of wet weight. To convert changes in pounds of nitrogen or phosphorus per ton of wet weight (ΔN_M^C) to tons of wet manure weight as excreted, we multiply by the ratio of the total tons of wet weight manure as excreted (WW^C) to the total pounds of nitrogen or phosphorus per ton of wet weight manure (N_M^C):

(H6) $$\Delta N_M^C \times \frac{WW^C}{N_M^C} = Change\ in\ tons\ of\ wet\ weight\ non - poultry\ manure$$

This gives us the change in weight wet non-poultry manure needed to reduce the elemental nitrogen by the amount required.

The total cost of reducing non-poultry manure is therefore:

(H7) $$P_{WW} \times (Change\ in\ tons\ of\ wet\ weight\ non - poultry\ manure)$$
$$= Cost\ of\ reducing\ non - poultry\ manure$$

The price to remove a pound of nitrogen in non-poultry manure (P_M^C) could therefore be written as:

(H8) $$P_M^C = \frac{WW^C}{N_M^C} \times P_{WW}$$

Like we do for non-poultry manure, we estimate the change in (elemental) nitrogen or phosphorus in poultry litter as excreted in pounds per ton of wet weight. To convert changes in pounds of nitrogen or phosphorus per ton of wet weight (ΔN_M^B) to tons of dry manure weight as excreted, we multiply by the ratio of the total tons of dry weight poultry litter as excreted produced on the farm (DW^B) to the total pounds of nitrogen or phosphorus per ton of wet weight litter (N_M^B).

(H9) $$\Delta N_M^B \times \frac{DW^B}{WW^B} = Change\ in\ tons\ of\ dry\ weight\ poultry\ litter$$

This gives us the change in dry wet poultry litter needed to reduce the elemental nitrogen or phosphorus by the amount required by a 15-percent reduction in nutrient applications to cropland.

The total cost of reducing poultry litter is therefore:

(H10) $$P_{DW} \times (Change\ in\ tons\ of\ dry\ weight\ poultry\ litter) = Cost\ of\ reducing\ poultry\ litter$$

The price to remove a pound of nitrogen or phosphorus in poultry litter (P_M^B) could therefore be written as:

(H11) $$P_M^B = \frac{WW^B}{N_M^B} \times \frac{DW^B}{WW^B} \times P_{DW}$$

Note that WW^C, WW^B, DW^B, N_M^C, and N_M^B differ by farm, hence the relationship between P_M^C and P_M^B will differ by farm. If a farm produces both poultry litter and non-poultry manure, it must compare P_M^C with P_M^B to understand which type of manure it would be cheaper to reduce (if need be).

Appendix I: Calculations for expository figure 18

Appendix Table I1: Assumed parameters for expository figure 18

Parameter	Value
Number of cows at dairy	400
Acreage of corn	200
National average yields per acre	123.4 bushels/acre
Price of corn per bushel	$6.89
Animal units per head of dairy cows	0.73
Tons of weight wet manure excreted per dairy animal unit	20.34
Proportion of manure that is recoverable	0.75
Pounds of N per ton of recoverable manure	12.92
Proportion of recoverable N in recoverable manure	0.40
Pounds of N used per bushel of corn	0.84
Ratio of amount of N needed to be applied for recorded yields to amount of N used by crop	1.4
Proportion reduction in N application to satisfy a 15-percent reduction in N applications to cropland	0.15
Number of credits generated per pound of N reduced	0.5
Dollars per credit	$20
Cover crops (cost per acre)	$62.80
Conservation tillage (cost per acre)	$22.34
Grass buffers (cost per farm)	$58.58
Barnyard runoff control (cost per farm)	$772.30
Animal waste management system (cost per farm)	$111.11
Mortality composting (cost per farm)	$787.87
Cost of NMP per acre	$29.90
Financial assistance proportion	0.50
Transaction costs	40 percent of baseline costs other than NMP implementation
Number of miles that manure must be shipped	34.2
Base charge per ton of manure to be shipped	$2.50
Per mile per ton charge of manure to be shipped	$0.38
Percentage yield loss from implementing a 15-percent reduction in nutrient applications to cropland after adopting a NMP	10 percent
Price per ton of anhydrous ammonia fertilizer	$783
(Pounds of N in fertilizer)/(pounds of fertilizer)	0.82
Pounds of N per ton of recoverable manure	12.92

See appendices A, C, D, and H and main text for explanations of parameter values and sources.
N = nitrogen; NMP = nutrient management plan;
Source: USDA, Economic Research Service.

Calculated values:
(Note that in order to avoid compounding rounding errors in final calculations, resulting values in each equation may not be exact.)

(I1) Number of animal units = (head) / (animal units per head of dairy cows)
=(400) / (0.73) = 548

(I2) Tons of manure excreted (in wet weight) = (dairy animal units) X (tons per dairy animal unit)
= (548) X (20.34) = 11,145

(I3) Tons of recoverable manure (in wet weight) = (tons of total manure excreted) X (recoverable tons of weight manure per ton of manure excreted)
= (11,145) X (0.75) = 8,359

(I4) Pounds of N in recoverable manure = (tons of recoverable manure) X (pounds of N per ton of recoverable manure)
= (8,359) X (12.92) = 107,997

(I5) Pounds of recoverable N in recoverable manure = (pounds of N in recoverable manure) X (proportion of recoverable N in recoverable manure)
= (107,997) X (0.40) = 43,199

(I6) Total yield of corn in bushels = (acres) X (bushels/acre)
= (200) X (123.4) = 24,680

(I7) Total pounds of N used by corn (uptake capacity) = (bushels) X (pounds of N used per bushel)
= (24,680) X (0.84) = 20,731.2

(I8) Total pounds of N applied to see recorded yields = (pounds of N used by corn) X (Ratio of amount of N needed to be applied for recorded yields to amount of N used by crop)
(20,731.2) X (1.4) = 29,024

(I9) Pounds of manure N needed to export to reach NMP = (pounds of recoverable N in recoverable manure) – (pounds of N applied to see recorded yields)
= 43,199 – 29,024 = 14,175

(I10) Shipping cost per ton of manure:
(base charge per ton) + [(per mile charge per ton) X (number of miles)]
= $2.5 + ($0.38 X 34.2) = $15.50

Gross benefits from credit sales

(I11) Credits from a 15% reduction in N application to cropland = (lb N applied) X (15%) X (Number of credits generated per pound of N reduced)
= (29,024) X (0.15) X (0.5) = 2,177

(I12) Gross benefits from credit sales = (credits generated) X ($/credit)
= (2,177) X ($20) = **$43,536**

Baseline costs other than NMP for crop-only farm

(I13) Baseline costs other than NMP for crop-only farm before financial assistance and transactions costs = (number of acres) X [(cost of cover crops per acre) + (cost of conservation tillage per acre)] + (cost of grass buffers per farm)
= [200 X ($62.80 + $22.34)] + $58.58 = $17,087

(I14) Baseline costs other than NMP for crop-only farm after financial assistance = (Baseline costs other than NMP for crop-only farm before financial assistance and transactions costs) X (financial assistance proportion)
= ($17,087) X (0.5) = $8,543

(I15) Baseline costs other than NMP for crop-only farm after financial assistance and transactions costs = (Baseline costs other than NMP for crop-only farm after financial assistance) X (1 + transactions costs percentage)
= ($8,543) X (1.4) = **$11,960**

Baseline costs other than NMP for dairy farm:

(I16) Baseline costs other than NMP for dairy farm before financial assistance and transactions costs = (number of acres) X [(cost of cover crops per acre) + (cost of conservation tillage per acre)] + (cost of grass buffers per farm) + (cost of barnyard run-off control per farm) + (cost of animal waste management system per farm) + (cost of mortality composting per farm)
= [200 X ($62.80 + $22.34)] + $58.58 + $772.30 + $111.11 + $787.87= $18,758

(I17) Baseline costs other than NMP for dairy farm after financial assistance = (baseline costs other than NMP for dairy farm before financial assistance and transactions costs) X (financial assistance proportion)
= ($18,758) X (0.5) = $9,379

(I18) Baseline costs other than NMP for dairy farm after financial assistance and transactions costs = (baseline costs other than NMP for dairy farm after financial assistance) X (1 + transactions costs percentage)
= ($9,379) X (1.4) = **$13,130**

Baseline costs – NMP for crop-only farm:

(I19) NMP planning cost before financial assistance and transactions costs = (number of acres) X (cost of NMP per acre)
= (200) X ($29.90) = $5,980

(I20) NMP planning cost after financial assistance = (NMP planning cost before financial assistance and transactions costs) X (financial assistance proportion)
= ($5,980) X (0.5) = $2,990

(I21) NMP planning cost after financial assistance and transactions costs: = (NMP planning cost before financial assistance and transactions costs) X (1 + transactions costs percentage)
= ($2,990) X (1.4) = **$4,186** = NMP implementation cost

Baseline costs – NMP for dairy farm:

(I22) NMP planning cost before financial assistance and transactions costs = (number of acres) X (cost of NMP per acre)
= 200 X $29.90 = $5,980

(I23) NMP planning cost after financial assistance = (NMP planning cost before financial assistance and transactions costs) X (financial assistance proportion)
= (5,980) X (0.5) = $2,990

(I24) NMP planning cost after financial assistance and transactions costs = (NMP planning cost after financial assistance) X (1 + transactions costs percentage)
= $2,990 X 1.4 = $4,186

(I25) NMP implementation cost (cost to ship excess manure off-farm) = (pounds of excess N in recoverable manure) X (tons of wet manure excreted/pounds of recoverable N in recoverable manure) X (shipping cost per ton of manure)
= 14,175 X (11,145/43,199) X ($15.50) = $56,671

(I26) Total NMP cost for dairy farm = (NMP planning cost after financial assistance and transactions costs) + (NMP implementation cost)
= $4,186 + $56,671 = **$60,857**

Yield change cost due to a 15-percent reduction in N applications to cropland:

(I27) Yield change cost due to 15-percent reduction in N applications to cropland = (percentage yield loss from 15-percent reduction) X (total yield in bushels) X (cost per bushel)
= 0.10 X 24,680 X $6.89 = **$17,005**

Fertilizer change cost due to a 15-percent reduction in N applications to cropland:

(I28) Fertilizer change cost due to a 15-percent reduction in N applications to cropland = (pounds of N reduced under 15-percent reduction) X (price per ton of anhydrous ammonia fertilizer) X (tons per pound) X (pounds of N in fertilizer)/(pounds of fertilizer)
= 4,354 X $783 X (1/2000) X (0.82) = **$2,079**

Manure change cost due to a 15-percent reduction in N applications to cropland:

(I29) Manure change cost due to 15-percent reduction in N applications to cropland = (pounds of N reduced under 15-percent reduction) X (tons of wet manure excreted/pounds of recoverable N in recoverable manure) X (shipping cost per ton of manure)
= 4,354 X (11,145/43,199) X ($15.50) = **$17,405**

Net benefits of credits:

(I30) Net benefits of credits = (gross benefits of credit sales) - (baseline costs other than NMP) - (baseline costs of NMP) - (yield change cost) + (fertilizer change savings) - (manure shipping costs to meet a 15-percent reduction in N applications to cropland)
Crop-only farm: $43,536 - $11,960 - $4,186 - $17,005 + $2,079 - $0 = **$12,463**
Dairy farm: $43,536 - $13,130 - $60,857 - $17,005 + $0 - $17,405 = **-$64,862**

Appendix J: Further Sensitivity Analyses

Appendix Table J1: Additional sensitivity analyses: effects of parameter and assumption changes from "base" scenario on percentage of possible participants finding it cost-beneficial to participate

		Change in parameter or assumption from "base" scenario										
Type of farm	**"Base" Scenario**	**0-percent loss in yield**	**5-percent loss in yield**	**15-percent loss in yield**	**50-percent transactions costs on baseline requirements**	**Alternate manure shipping distances 1**	**Alternative manure shipping distances 2**	**2007 crop prices**	**2009 crop prices**	**2007 fertilizer prices**	**2009 fertilizer prices**	**Large AFOs in all states have prior regulation**
		Percent										
All	**62**	**70**	**66**	**57**	**60**	**62**	**62**	**64**	**65**	**62**	**63**	**62**
No livestock -- Less than 100 acres of cropland	73	82	78	66	70	73	73	75	76	73	74	73
No livestock -- 100 or more acres of cropland	93	96	95	89	91	93	93	94	94	92	93	93
Some livestock but not likely to be confined	43	51	47	38	40	43	43	44	45	42	43	43
Small AFOs	89	93	91	84	87	89	89	90	91	88	89	89
Without excess	92	96	94	88	91	92	92	93	94	92	92	92
With excess	36	46	43	28	33	36	36	39	42	36	36	36
Medium AFOs	79	82	81	75	78	78	78	80	80	79	79	79
Without excess	99	100	100	99	99	99	99	99	99	99	99	99
With excess	54	62	58	47	53	53	53	56	57	54	54	54
Large AFOs	78	83	81	74	77	78	78	80	80	78	78	88
Without excess	100	100	100	99	99	100	100	100	100	100	100	100
With excess	59	68	64	51	57	58	58	63	63	59	59	77

AFO = animal feeding operation.

Source: USDA, Economic Research Service calculations based on USDA, National Agricultural Statistics Service, 2012 Census of Agriculture.