Differences between Livestock and Crop Producers' Participation in Nutrient Trading

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As part of the method to meet the 2010 Chesapeake Bay Total Maximum Daily Load (TMDL), the U.S. Environmental Protection Agency (EPA) is promoting nutrient trading within Chesapeake Bay states (Chesapeake Bay Commission 2012; Branosky, Jones, and Selman 2011). Nutrient trading is a market-based mechanism that theoretically can reduce pollution levels less expensively than uniform mandates on technology adoption. In such a program, a cap is placed on the total amount of pollution that can be released over a certain time period to a water body, and regulated entities are each assigned a limit on what they are permitted to discharge. In the event that a regulated polluter wants to emit more than its limit, it can purchase credits representing nutrient discharge reductions from other regulated or unregulated polluters.[1]

The four nutrient trading programs already adopted in Chesapeake Bay states allow trading to occur between regulated "point" and unregulated "non-point" pollution sources. Point sources are characterized by pollution originating from distinct outlets like pipes, tunnels, or ditches, while non-point sources emit from non-discernible areas like agricultural fields or parking lots.[2] In much academic literature and guidance documents on nutrient trading programs, agriculture is characterized as an unregulated non-point source supplier of pollution reduction credits (for example, Jones *et al*, 2010; Ribaudo and Gottlieb, 2011). Further, agricultural credit suppliers are often described as crop producers who reduce commercial fertilizer application or alter land uses to limit nutrient run-off.

The characterization of agricultural operations as unregulated non-point source fertilizer appliers overlooks the contribution of land-applied manure to Bay pollution. The EPA estimates that land-applied manure contributes approximately half of agricultural nutrient loadings to the Bay (2009b). This suggests that including manure appliers in nutrient trading would be beneficial for Chesapeake Bay water quality.

[1] For purposes of this article, we use the term "credits" to refer to any obligation to supply a unit of nutrient discharge reduction. Pollution trading mechanisms generally distinguish between "offsets," which are units of nutrient discharge reduction supplied by unregulated entities and sold to regulated entities, and "credits," which are bought and sold between regulated entitles. Both types of obligations are purchased so that capped entities can meet their discharge limits.

[2] "Regulation" in this context refers to environmental policies prescribing specific practices to limit pollution discharges to waterways.

The focus on crop producers also overlooks at least two ways that livestock producers may participate in nutrient trading differently. First, complicated Clean Water Act (CWA) rules govern livestock operations deemed Concentrated Animal Feeding Operations (CAFOs), which are agricultural operations generating both regulated point and unregulated non-point source discharges. Adding to the confusion is a 2011 lawsuit ruling stating that only CAFOs with prior discharges need to obtain permits. Ignoring the CWA CAFO rules potentially obscures how individual livestock operations may participate in nutrient trading, and yields questions as to whether CAFOs can buy nutrient credits to meet their regulatory requirements, whether they can generate credits from their discharge reductions, and whether they can reduce their non-point source discharges to satisfy their point-source reduction requirements.

A second difference between livestock and crop producers' participation in nutrient trading arises from the different costs of limiting manure versus fertilizer applications. One way agricultural participants may generate credits is by reducing land application of nutrients in the form of fertilizer or manure. Crop producers are more likely to use commercial fertilizer; reducing its use lowers expenses. Livestock producers often use manure produced at the operation; reduction often means shipping manure off-site, increasing expenses. Crop producers can reduce fertilizer use, thereby lowering expenses. However, livestock producers may ship manure off-site, increasing expenses. The costs to reduce land application may therefore differ between the two types of producers.

In this article we first generate indicators of the relative contribution of livestock operations to Chesapeake Bay nutrient loadings from 2007 Census of Agriculture data. While estimates of land-applied manure's impact on Bay pollution are publicly available, contributions by type of agricultural producer are not (to our knowledge). Such estimates are useful from a policy implementation perspective and in understanding the importance of including confined livestock operations in nutrient trading schemes. We find that potential CAFOs account for nearly two-thirds of manure-applied acres in the Chesapeake Bay. As land-applied manure contributes approximately half of Chesapeake Bay nutrient loadings, this finding suggests the CAFOs play an important role in reducing nutrient pollution.

Given this finding, we next explore how federal CAFO rules influence how livestock producers theoretically participate in Chesapeake Bay nutrient trading.[3] Such information is useful for individual livestock facility operators, researchers modeling nutrient trading, and policy-makers designing trading programs.

Turning from the effects of CWA rules to the costs of manure disposal, we next develop a model for agricultural producers' decision to participate in nutrient trading and then simulate prospective participation for all farms in the 2007 Census of Agriculture. In particular, we examine how the net value of nutrient reduction credits depend on differing program entry costs, changes in crop yields, fertilizer expenditures, and cost of manure export.

We find that the interaction between CAFO regulations and nutrient trading program rules may affect the relative costs of livestock versus crop producers' entry into trading programs. Permitted CAFOs may already meet many of the requirements for program entry, giving them a potential early entry advantage. However, historical reticence to examination by permitting authorities may signify high non-priced costs related to fear of government oversight. The 2011 lawsuit finding may make currently unpermitted facilities less willing to approach a regulatory authority to sign up for trading, for fear of discharge documentation. The costs specific to nutrient trading entry may therefore be different for certain livestock operations than for crop-only producers, particularly small- and medium-sized CAFOs that are generally only regulated at the discretion of the regulatory authority. We estimate that CAFOs are less likely to participate in nutrient trading, due in part to the higher costs of reducing land applications from exporting manure.

Nutrient Pollution from Agricultural Operations

[3] Nutrient trading programs can take several forms, and a unified Chesapeake Bay nutrient trading program has not yet been established. Instead we use guidance documents from the EPA (2009) and the EPA's Chesapeake Bay Program (2009) to describe elements of a potential Chesapeake Bay-wide nutrient trading program.

The effect of agricultural production on water quality has been well-documented (for reviews see Burkholder *et al* 2007; Ribaudo and Johansson 2006). In a 2002 assessment of the nation's waters, the EPA found that agriculture was the top polluter of rivers and streams, implicated in over 35 percent of impaired waters (EPA 2002). Polluted run-off from agricultural operations has also been linked to coastal dead zones, fish kills, impaired drinking water supplies, and adverse public health outcomes (Copeland 2006). In the Chesapeake Bay, the EPA estimates that agriculture is implicated in 38 percent of nitrogen and 45 percent of phosphorus loadings; land application of livestock manure accounts for 17 percent of the nitrogen and 26 percent of the phosphorus loadings (or 45 percent and 58 percent of the *agricultural* nitrogen and phosphorus loadings) (EPA 2009b).

One factor implicated in nutrient pollution from agriculture is arguably the increasing disaggregation between crop and livestock production both at the farm and region level (Kellogg, Lander, Moffitt, and Gollehon, 2000). Manure is no longer heavily used as a fertilizer; for example, between 2003 and 2006 only 10 percent of U.S. acreage in eight major crops received manure (Ribaudo *et al*, 2011). Instead, crop producers purchase manmade fertilizers which have better nutrient consistency and can more readily be tailored to individual crops' needs. If this fertilizer is applied inappropriately, precipitation can wash excess nutrients into surface- and ground-water.

Manure also yields water quality concerns. Livestock production has increasingly moved to very large-scale confinement operations with thousands of animals on a relatively small amount of land, generating a great deal of manure in relation to the surrounding cropland's absorptive capacity. Much of this manure is scraped or flushed from animal raising areas into storage facilities, including manmade earthen ponds, concrete or steel tanks, and manure stacks. Often, livestock facility operators apply the stored manure to what cropland is available on the operation.

Water pollution can arise when manure storage facilities leak or flood, or if manure is land-applied at rates above which soil and plants can absorb (Gollehon and Caswell 2000). To avoid this, livestock facility operators may ship manure to other locations. However, transporting manure off-farm is expensive and crop farmers' willingness to pay for or even accept manure is often low. Hence, manure has little value in many regions, creating an incentive for some livestock producers to treat it as a waste and apply it inappropriately.

These trends in excess manure nutrients are prominent in the Chesapeake Bay area. Using 1997 Census of Agriculture data, Kellogg and coauthors (2000) found several county clusters within the Bay states that generate more manure nutrients than they have cropland and pastureland on which to agronomically assimilate. More updated research finds similar "manure hot spots" in the Shenandoah Valley, the DelMarVa Peninsula, and Lancaster County, Pennsylvania (Chesapeake Bay Foundation, 2004).

Clean Water Act Regulations of Livestock Operations

While both crop and livestock operations potentially pollute water, the CWA only regulates certain types of livestock operations called CAFOs. CAFOs are livestock operations that confine animals over a certain number of days per year and satisfy size and/or discharge requirements. CAFOs that discharge must obtain National Pollution Discharge Elimination System (NPDES) permits. Originally instituted in 1972, the CWA CAFO regulations have been updated numerous times, most recently in 2011 (77 FR 44494-44497). The CWA sets a minimum level of regulation; enforcement is devolved to the states, which can also adopt their own more stringent rules. As nutrient trading programs generally require participants to satisfy all regulations before buying or selling credits, understanding the CWA CAFO rules is pertinent for comprehending how livestock operations may engage in Chesapeake Bay nutrient trading. More detail can be found in appendix A.

Under the federal regulations, farms with livestock are first characterized by whether or not they are "animal feeding operations" (AFOs) (see appendix figure A1 for a diagram of livestock operation types characterized according to CAFO rules). AFOs must have animals confined for 45 days or more in any single year and not grow crops in the area of the facility where animals are raised and manure is stored (called the "production area").[4] Once classified as an AFO, a livestock

[4] AFOs can grow crops in other areas of the facility, just not the production area. The area where crops can be grown is referred to as the "land application area," described below.

operation can be further categorized as a CAFO, depending on size and discharges. CAFO size is characterized according to the number of animals at the operation (see appendix table A1), and permit requirements vary by size.

AFOs that are "large" are automatically "large CAFOs." Medium-sized AFOs are *defined* to be "medium CAFOs" if they discharge via a manmade conveyance or if animals at the operation come into contact with federally regulated waters. Small and medium AFOs may be *designated* as CAFOs at the discretion of the regulating authority. This ability of the regulatory authority to designate small and medium AFOs as CAFOs often makes it difficult to ascertain which facilities of these sizes are required to obtain permits.

Even if an AFO is defined as a CAFO, it may not need to obtain a permit. A 2012 rule revision stated that a CAFO did not need to apply for a permit if it had not had a discharge, striking down earlier requirements that CAFOs get permits if they had "a potential to" or "proposed to" discharge (77 FR 44494-44497; Centner and Newton 2011).

The CAFO permit divides the livestock facility into two parts, pertinent for classifying discharges as "point" or "non-point." First, the "production area" is the vicinity where the livestock are held and where manure is stored and processed. Second, the "land application area" is comprised of crops and pastures under control of the CAFO operator where manure or wastewaters are applied.[5] Note that the regulatory description of the land application area does not cover lands that are *not* controlled by the CAFO operator but on which CAFO-generated manure is applied. Thus federal CAFO regulations do not govern operations that apply manure but do not raise livestock.

The federal CAFO permit includes requisites for the production and land application areas. The production area must function such that it can contain wastes inclusive of precipitation from rare, large storms. If a permitted CAFO is abiding by these stipulations, then it can discharge from

[5] The land area around the production area but not used for manure application is not directly referenced in the federal CAFO permit, but is a feature of Chesapeake Bay nutrient loading calculations (see, for reference to this, Water Quality Goal Implementation Team, 2011). This area is considered a potential source of non-point source pollution in Chesapeake Bay models of nutrient loadings.

the production area, and such effluent is considered a point-source discharge. Since the permitted facility can only discharge from the production area in unlikely conditions, the CAFO permit is characterized as "no discharge." A 2012 rule amendment found that if an unpermitted CAFO discharges from its production area it cannot be fined for failure to apply for a permit, only for the unpermitted discharge.[6]

With regards to the land application area, the CAFO permit requires the implementation of a Nutrient Management Plan (NMP) that follows specific guidelines, including minimizing nutrient run-off, sampling of manure and soil, periodic inspection of land application equipment, and set-back distances (EPA 2003, p. J-9). Regardless of whether a CAFO has had a discharge and needs to obtain a permit, if it has instituted an NMP it can have run-off from the land application area due to normal precipitation. These land application area discharges are considered "non-point source" and are excluded from permit oversight based on an exemption barring regulation of agricultural storm-water.[7]

The federal NPDES CAFO permit allows for additional stipulations on the production area in the event that a water body is not reaching its desired quality level. While there are no additional stipulations for CAFOs under the Chesapeake Bay TMDL, understanding the difference between what is normally required in the permit and the additional stipulations under a TMDL is necessary for understanding nutrient trading, described below.

CAFO Contributions to Chesapeake Bay Nutrient Loadings

An assessment of CAFOs' relative contribution to Chesapeake Bay nutrient loadings illuminates the relative effects of potentially dissuading livestock operations from nutrient trading. We are not aware of any estimates of the full contribution of CAFOs' point and non-point source discharges to Chesapeake Bay nutrient loadings. The EPA loading estimates from manure (EPA 2009b) include all land appliers of manure, not just CAFOs. Where projected loadings attributed to CAFOs can be

[6] This 2012 rule amendment occurred in response to the 2011 lawsuit mentioned above and described in Centner and Newton (2011).
[7] These discharges are also not attributed to CAFOs in the Chesapeake Bay nutrient loading calculations; instead they are included in the "agricultural non-point source" category along with run-off from non-CAFO facilities.

found, they refer only to point-source discharges from permitted facilities, excluding unpermitted facilities and non-point source discharges (see Chesapeake Bay Commission, 2012; personal communication, Katherine Antos, EPA, June 8, 2012). As EPA data from 2011 suggest that only three-quarters of large CAFOs in the Chesapeake Bay states had permits, even the point source pollution is underestimated (EPA 2011).

Another reason to examine pollution level according to CAFO status rests on considering nutrient reduction at an operation rather than a field level. Many models of agricultural pollution control consider farmer decisions regarding individual acres (for example, Ribaudo *et al*., 2011). However, CAFO regulation occurs at the operation, rather than field, level. Hence a crop-only producer applying manure may face a different cost-benefit calculus from a CAFO operation doing the same. Finally, from a policy implementation perspective, it may be more cost-effective to involve few large dischargers than many small ones. Such a strategy involves looking at pollution according to operation rather than field.

To provide some indications of the relative input of CAFOs to nutrient loading in the Chesapeake Bay, we use 2007 Census of Agriculture data and involved methods developed by the National Resource Conservation Service (NRCS). We characterize types of farms according to livestock confinement and size, manure nutrients produced, and the capacity of the crops grown and pastureland to absorb nutrients. The NRCS methodology is described in Kellogg *et al* (2000) (hereafter KLMG) and Kellogg, Moffitt, and Gollehon (2012) (hereafter KMG). We describe this methodology and our divergences from it in Appendices B-F.

We classify farms according to small and large crop-only farmers without livestock, farms with only pastured livestock, and potential CAFOs according to size class.[8] Table 1 shows that CAFOs cover a large and disproportionate share of manure acreage. Although they constitute only 15 percent of all agricultural operations and cover only 31 percent of cropland and pastureland in the Chesapeake Bay watershed counties, potential CAFOs control 66 percent of manure applied

[8] As noted in a GAO report (2008), data on CAFO status is lacking. We follow detailed methods described in KMG and KLMG to characterize farms as potential AFOs. We refer to "potential" CAFOs because we do not have information on which operations are characterized as such by the EPA.

acres. Small and medium CAFOs account for 59 percent of manure acreage. Crop-only producers cover a larger share of fertilized acreage and a smaller percentage of manure-applied acres.

A further understanding of the relative pollution from CAFOs comes from the estimated amount of "recoverable" manure nutrients generated at each farm and the amount of nitrogen that could be applied without excessive nutrient build-up in the soil at each farm, given crop yields. "Recoverable" in this scenario refers to the ability to capture the manure nutrients and apply them to land. Following the NRCS, we assume that operations without confined livestock do not produce any recoverable manure nutrients as their manure management methods generally do not lend themselves to collecting wastes. See Appendices D- F for more detail.

Table 2 provides estimates of the amounts of nitrogen assimilative capacity and the amount of recoverable manure nitrogen produced by type of agricultural operation in the Chesapeake Bay watershed. While potential CAFOs constitute 39 percent of estimated uptake capacity, they generate all of the recoverable manure nutrients (by assumption). Small and medium potential CAFOs generate the large majority (89 percent) of the recoverable manure nitrogen. Comparing the average uptake capacity and nutrients generated by type of farm, we see that CAFOs often generate more manure than they can assimilate on their land.

These estimates of manure acreage, manure nutrient production, and assimilative capacity suggest that potential CAFOs contribute a disproportionate and large share of nitrogen pollution to the Chesapeake Bay watershed. As mentioned above, the EPA estimates that land-applied manure contributes nearly half of agricultural nitrogen loadings to the Chesapeake Bay (EPA 2009b). Potential CAFOs control 66 percent of manure-applied acres but only constitute 15 percent of farms, suggesting that policy dollars might be well-spent targeting these operations. In particular, small and medium CAFOs cover a large percentage of manure acreage as well as manure nutrients produced. As these operations largely fall outside of regulatory scrutiny, including them in nutrient trading may be beneficial to lowering loadings to the Bay.[9]

[9] While these estimates provide indications of the relative contribution by CAFOs, they do not include factors related to run-off control. If, for example, CAFOs are more likely to institute nutrient management than crop-only producers, this may counteract their disproportionate manure acreage and production. However, given prior

Nutrient Trading Under the Prospective Chesapeake Bay Program

Characteristics of both real and hypothetical nutrient trading systems vary; in this section we outline the relevant features of the Chesapeake Bay program described by the EPA (2009a) and the EPA's Chesapeake Bay Program (2009). The literature on nutrient trading generally describes two distinct types of polluters: point and non-point sources. Point sources discharges are regulated, typically require expensive technological upgrades to reduce, and are more easily measured and verified. Non-point source discharges are unregulated, require less expensive pollution abatement, and are difficult to measure and therefore verify (Nelson 2005). Non-point source discharge reductions are often operationalized via specific practices assigned reduction amounts by the trading authority; to account (in part) for measurement uncertainty, the tallied reduction is often a portion of the actual expected reduction.[10]

The Chesapeake Bay TMDL establishes a limit on the amount of pollutants that can be discharged into this water body and its tributaries. Individual contributors to the limit are each assigned a permitted amount of discharge. The proposed Chesapeake Bay nutrient trading program guidelines allow trading between point sources and between point and non-point sources.

Consider the discharge levels from a permitted non-CAFO point source in the Chesapeake Bay; call this PS1 (figure 1). Prior to the TMDL, the permit for PS1 requires technology standards yielding a discharge level of 30. However, the TMDL requires PS1 to limit discharges to level 20, called the discharger's "baseline."[11] In the absence of nutrient trading, PS1 would have to pay $600 to install expensive discharge control technologies to reach 20 from 30. PS1 can reach its baseline either by reducing its discharges or buying credits from other regulated point source or an

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research suggesting that manure appliers are less likely to institute nutrient controls (Ribaudo *et al*, 2011), and given that CAFOs are more likely to apply manure, this seems unlikely.

[10] A "trading ratio" refers to the number of units of reduction per credit generated. Also note that the loading amount that is actually reduced may differ from the amount assigned by the trading authority. The trading authority may apply an average reduction amount to the practice, or may use an incorrect measure.

[11] Some research on pollution trading refers to the level at which the polluter currently discharges as the "baseline." Note that we follow EPA guidance documents and refer to the lower level of discharge required under the TMDL as the "baseline."

unregulated non-point source. For discharge reductions below 20, PS1 could generate credits to sell to other regulated point-source dischargers.

Suppose that a second point source (PS2) faces the same baseline and permitting requirements as PS1, but it is not compliant with its pre-TMDL effluent limit and discharges at level 40. In these circumstances, Chesapeake Bay nutrient trading guidelines from the EPA state that PS2 could *not* buy credits to reach level 30 from level 40.[12]

Next consider a non-point source like a crop-only producer in the Chesapeake Bay (NPS1). NPS1 is not subject to CWA permitting requirements and is discharging at level 30 in figure 2 (note that the discharge levels are not meant to be indicative of actual levels or comparisons between point and non-point source polluters). If NPS1 wants to generate nutrient credits to sell, the trading program requires it first to institute certain practices that place its discharges at a lower level, again called its "baseline"[13]; suppose NPS1's baseline is 20, and the reduction from level 30 to level 20 costs $100. NPS1 can then institute additional nutrient management practices and reduce its discharges to level 10 from 20 at a cost of $200. NPS1 can then sell 10 credits to PS1, and would be willing to do so for a price greater than $300. PS1 would be willing to buy these credits if they cost less than $600. Suppose PS1 and NPS1 agree on a price of $400. PS1 could use these credits to reach discharge level 20. PS1's cost ($400) would be lower than it would have had to pay without nutrient trading ($600). Further, NPS1 gains a profit of $100. The example illustrates that with trading, the overall discharge level can be reduced to the no-trading level but at a lower overall cost.

Interaction of CAFO Laws with Chesapeake Bay Nutrient Trading

The above description of nutrient trading distinguishes between point and non-point sources. However, CAFOs generate *both* these types of discharges, complicating their participation in nutrient trading programs.

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[12] Other nutrient trading programs may have different rules with respect to this point, and may allow dischargers to meet their pre-TMDL regulatory permit obligations by purchasing credits.

[13] Note that unlike the point sources, the non-point source is not required to reach its "baseline" under the TMDL. The non-point source just needs to reach its baseline if it would like to participate in nutrient trading.

CAFOs with Permits

Permitted CAFOs can legally generate point source discharges from both their production areas and non-point source discharges from their land application areas. Figure 2 provides a schematic of discharge levels pertinent to the different areas of CAFOs. If a permitted CAFO is in compliance with the production area requirements in its permit, the only discharges it is allowed (and theoretically has) are those related to rare, major storm events. Under "normal" circumstances the CAFO would have no discharges from its production area (a discharge level of zero). Since there are no additional discharge reduction requirements for CAFOs under the Chesapeake Bay TMDL, this operation does not have to reduce its point-source effluent further.

Now consider the non-point source discharge levels pertinent to the land application area of the permitted CAFO (right-hand side of figure 2). Suppose the CAFO is operating in compliance with its land application permit requirements and generates non-point source discharges of 20. If the CAFO institutes further nutrient management measures beyond its permit requirements, it could reduce its discharges from its land application area below the baseline to level zero. Theoretically, the permitted CAFO could then sell 10 credits (although it would not be able to sell credits from moving from the current level to the baseline). If the price of the credits was greater than the cost to reduce the discharges from 20 to zero, then the permitted CAFO would have an economic incentive to participate in nutrient trading by selling credits generated from its land application area.

The CAFO discharging at level 30 where it is not in compliance with its land application permit requirements could not buy credits to reduce its discharge level to 20 (again according to the EPA's descriptions of a Chesapeake Bay nutrient trading program). Thus the permitted CAFO could enter a nutrient trading program as a seller of credits from its land application area, but not as a buyer.

To summarize, the permitted CAFO could theoretically generate discharge reduction credits from its land application area, much like a crop-only producer. It could not generate credits from its production area because its permit is "no discharge" and it cannot reduce something it does not have. Because the CAFO permit has not further stipulations under the TMDL, the permitted CAFO would have no need to buy credits. Hence CAFO operators could not reduce discharges from the land application area and "sell" these reductions to itself to meet discharge requirements in its production area. Since it already has a permit, the CAFO would be in compliance with federal and state laws and would only need to institute any additional measures in order to reach the baseline to participate in nutrient trading.

CAFOs without Permits and non-CAFO AFOs

If an unpermitted CAFO has an NMP and other nutrient run-off controls, then discharges from the land application area during regular precipitation are exempt from regulation. It could reduce discharges from its land application area beyond the baseline level and theoretically sell these as credits, like the permitted CAFO. In figure 2, if the unpermitted CAFO was discharging at level 20 from its land application area and reduced to level zero, it could sell 10 credits.

If the unpermitted CAFO would like to sell these credits, it must approach the trading authority. The nutrient trading program authority may examine the production area of the CAFO to make sure it is in compliance with applicable laws. Suppose this an unpermitted CAFO were found to be discharging from its production area at level 10 (left-hand side of figure 2). Under the EPA's descriptions of a Chesapeake Bay nutrient trading program, a point-source discharger cannot meet its pre-TMDL regulatory requirements through purchase of credits (EPA 2009a); to comply with its permit, the CAFO discharging from its production area at level 10 could *not* buy 10 credits to reach level zero from level 10. If the unpermitted CAFO approaches the nutrient trading authority and states that it has a production-area-discharge that it would like to reduce and therefore sell as credits, it could be fined for having unpermitted discharges. Hence the unpermitted CAFO could not be a buyer of credits.

An alternative for the non-permitted CAFO would be to separate its livestock and crop operations and place them under separate ownership. Recall that under the federal CAFO rules, the land application area includes only those fields that are owned by the CAFO.[14] Thus, if a CAFO were to reorganize such that the livestock operation exported all manure off of the operation to a newly-formed entity under another's ownership, it would avoid any federal concerns regarding appropriate land application. However, individual states may adopt their own rules on manure application, eliminating any incentive to divide the livestock and crop portions of a CAFO.

The non-CAFO AFO would face many of the same decisions as a non-permitted CAFO when deciding whether to participate in a nutrient trading program. Recall that any AFO can be designated as a CAFO by the permitting authority. Thus a non-CAFO AFO approaching the authority could conceivably be designated as a CAFO and be required to obtain a permit and fined for any unpermitted discharges. If it were not designated as a CAFO, a non-CAFO AFO could theoretically participate in a nutrient trading program in a manner similar to non-AFO agricultural producers.

Effects of CAFO Rules on the Costs of Meeting Nutrient Trading Baseline Requirements

Because of the CAFO rules, some livestock operations will have different experiences from crop producers participating in nutrient trading. One difference is in the additional practices needed to reach the baseline. Appendix table A2 provides a comparison of the large CAFO permitting requirements as well as those required to meet the nutrient trading baseline in the four Chesapeake Bay states that have established trading programs. Many of the CAFO regulatory stipulations are also baseline requirements for the nutrient trading programs. For example, CAFOs are required to implement nutrient management plans (NMPs) as part of their permits in all states; NMPs are also required to meet nutrient trading baseline criteria. CAFOs already satisfying permits or already implementing NMPs may face fewer start-up costs to nutrient trading than unpermitted CAFOs and crop-only producers. Thus permitted facilities may be able to engage in nutrient trading more quickly and take advantage of any potential gains to early entry.

[14] However, two small or medium AFOs with common ownership in separate locations using the same land application area may be defined as a large CAFO, depending on the total number of animals. The same is true for AFOs under common ownership that adjoin each other.

Differences may also occur between states. States requiring all CAFOs to obtain permits (not just the ones that discharge) or with a strong program of documenting discharges would conceivably have more operations entering nutrient trading programs, relative to states with less stringent laws. Differing state rules may mean that livestock and non-livestock producers vary in their ability to generate credits from the same behaviors. Alternatively, one state may require large CAFOs to install certain nutrient management practices beyond federally mandated ones while another state may consider these practices to generate credits.

While the CAFO permitting process may provide an advantage in certain respects, it also adds some risk for livestock producers' participation in nutrient trading. If unpermitted operations that confine livestock face additional scrutiny with regards to the CAFO rules, this may impose an additional cost to their participation. These costs include both tangible ones such as adjustments to the manure storage facility, permitting fees, and possible fines, and the less-easily quantified ones related to fear of future regulation. Even if the unpermitted livestock operation were not compelled to get a permit prior to generating credits, participating in nutrient trading may increase the future probability of regulation. Once beginning nutrient trading, the unpermitted facility would reveal its existence and discharge level to the trading authority. Given that livestock producers have historically been strongly reticent to obtaining permits (see, for example, NRDC 1998) and a number of livestock lobby groups have sued the EPA over prior federal requirements to obtain permits, the costs of regulatory scrutiny may be pronounced.

Model of Nutrient Trading Participation through Enhanced Nutrient Management

To examine the potential differences in nutrient trading participation for crop-only versus livestock producers, we develop a model incorporating the benefits and costs of nutrient credit generation. In future sections we parameterize this model and apply it to the Census of Agriculture data described above.

The CWA rules may provide a comparative advantage to permitted CAFOs in terms of the costs of initially meeting baseline requirements. However, differences may arise between crop and livestock producers in the costs to reducing nutrient run-off (and therefore generating credits), based on how each producer type values nutrients. Research suggests that farmers who apply fertilizer differ in their nutrient management practices from those who apply manure (for example, Ribaudo *et al* 2011).

While there are multiple methods whereby livestock and crop producers may generate nutrient credits, we model just one to highlight differences between fertilizer and manure appliers. Enhanced nutrient management (hereafter ENM) requires producers to reduce nutrient application on all fields by 15 percent beyond the amount allowed in a nutrient management plan.[15] The Chesapeake Bay Foundation (2004) argues that ENM is one of the most cost-effective strategies for reducing nutrient pollution to the Bay, and the NRCS sponsored a $650,000 grant to study ENM in the Chesapeake Bay (Morrill, 2008).

We model the decision to enter nutrient trading as additive to the operation's production and consider only the costs and benefits in the first year of program entry rather than the entire life-cycle of credits. This incorporates the implicit assumption that producers will only enter the program if they see a positive return in the first year. In part, this addresses concerns with the risk inherent in future prices and multi-year contracts, which we do not address.

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:

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

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.

The cost of meeting the baseline is the cost of performing whatever requirements are necessary beyond what the farmer is already doing. When we apply the model to the data, we assume certain practices as necessary for meeting the baseline.

[15] This is a 15 percent reduction of the amount of nitrogen applied to each field, not a 15% reduction in the overall use of nitrogen fertilizer (which could conceivably be achieved by completely eliminating all nitrogen applications on a few acres).

The cost of generating credits depends in part on the fact that in all Chesapeake Bay states with nutrient trading program, a NMP is required to meet the baseline. A NMP requires that a producer apply nutrients in an agronomic fashion, so the 15 percent reduction from ENM will mean reducing applications below rates required in an NMP. For producers generating manure, meeting the NMP portion of the baseline will require them to export any manure nutrients in excess of the operation's agricultural field's absorptive capacity. This exported manure can be land applied on other farms within the watershed, shipped outside of the watershed for land application or other uses, land applied outside of the agricultural sector (for example, on public lands), or diverted to other uses aside from land application (like combustion and power generation).

We assume that the reduction in nitrogen applications will lead to lower yields and that elemental nitrogen from fertilizer is completely substitutable for elemental nitrogen from manure.[16] Allow $\overline{N}$ and N to be the totals amounts of nitrogen applied before and after ENM (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 nitrogen ($\overline{N}$) 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 ENM will be $Y_k(\overline{N}) - Y_k(N)$.

The sum of the amounts of nitrogen from fertilizer and manure applied ($\overline{N_F}$ and $\overline{N_M}$) equals to the total amounts applied: $\overline{N_F} + \overline{N_M} = \overline{N}$. Likewise the amounts applied after ENM (N_F and N_M) sum to the total (N): $N_F + N_M = N$.

Reductions in fertilizer use will yield lower expenses as the producer purchases less. Reductions in manure produced on-farm and related to meeting the ENM will entail shipping manure to other sites; the cost will be an additional transport costs. Hence reductions in fertilizer will yield negative costs and exporting manure will add costs.

We assume that livestock producers are not paid for their excess manure, and instead must bear the cost of moving it off-site. This assumption comes from prior analyses by Ribaudo and

[16] Note that we do not assume that a ton of manure and a ton of commercial fertilizer contain the same amount of nitrogen. In estimating the amount of nitrogen in manure, we make many adjustments to account for that fact that only a portion of manure is comprised of nitrogen and not all of it is readily available to crops.

coauthors (2003), who modeled Chesapeake Bay farmers' "willingness-to-accept" manure, rather than any price they were willing to pay for it.

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

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

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

We assume that the producer does not raise nitrogen 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:

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

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.

How much these factors affect the net value of credits depends on their relative prices in relationship to the other costs (of meeting the baseline and reduced yields) and the benefits generated from selling credits. To provide some understanding of these relative costs, we parameterize the model and then apply it to data for all agricultural operations in the Chesapeake Bay watershed.

Model Variables and Parameters

We parameterize the model using information from a variety of sources and apply it to 2007 Census of Agriculture data for Chesapeake Bay watershed counties in order to generate estimates of participation in, costs of, and benefits from nutrient trading for different types of farms. We develop a "base" set of parameter values and assumptions and present results using this set in the main text, but show several sensitivity checks in appendix I incorporating variations from the "base" scenario.

We assume the baseline requirements for participation include NMPs, soil conservation plans, and reductions in per-acre loadings; we chose these practices because they are part of the baseline requirements for current nutrient trading program in individual Chesapeake Bay states (see appendix table A2). We assume the reductions in per-acre loadings are achieved by implementing certain best management practices (BMPs). The most cost-efficient BMPs that would enable per-acre load reductions to the level of the baseline depend on the location of the farm, the current practices employed, and a host of other factors. Since we do not have enough information to model which BMPs would be best for each farm, we assume that farms must adopt conservation tillage, cover crops, and grass buffers (three such BMPs) to satisfy reductions in per-acre loadings.

We use information from the University of Maryland Environmental Finance Center (undated) to price nutrient management plans, cover crops, and conservation tillage at $3, $7.5, and $2.5 per acre per year, respectively; these prices represent farmers' share of annual costs and account for subsidies from government sources. We assume farmers can use government cost-sharing programs to meet baseline requirements but not to generate credits; this is true for individual Chesapeake Bay states' nutrient trading programs.[17]

Since NMPs are required for CAFO permits, we assume that large CAFOs have already fulfilled this baseline stipulation. As such, we assume that large CAFOs already ship excess manure nutrients off-farm and do not include these shipping costs as part of large CAFOs' costs to meet the baseline. In appendix I we show results where we do not make this assumption. We assume that small and medium potential CAFOs do not have permits and are therefore not yet following nutrient management plans. Hence they must pay the $3 per acre nutrient management plan cost as well as the costs of shipping excess manure off-farm (to meet the agronomic application rate of the NMP).[18]

Farmers generate credits by reducing the application of nitrogen after meeting the baseline requirements. Under ENM, the amount of nitrogen reduced is 15 percent of the amount of

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[17] Additional BMPs such as grass buffer strips can be paid for completely by government cost-sharing programs, so we do not include these in costs seen by farmers in meeting baseline requirements.
[18] If instead of shipping manure off-farm to meet the agronomic application rates on the field, a manure producer builds more storage, this will also add costs and lower the value of the credits for manure generators. However, we do not model this alternative.

nitrogen applied at agronomic rates. We assume that agronomic rates refer to having the nutrient applications match the operation's assimilative capacity. The amount reduced is not equal to the number of credits generated. Because non-point source pollution reductions are difficult to measure precisely, nutrient trading programs generally establish a trading ratio whereby each unit of reduction is only worth a partial credit. We assume a 2:1 trading ratio, meaning each unit of reduction equals half a permit. Following World Resources Institute (WRI) publications about nutrient trading in the Chesapeake Bay, we set the credit price in our "base" scenario at $20 per pound of nitrogen (Talberth *et al*, 2010a and 2010b).[19] We also examine participation at other credit prices; results are shown in appendix I and discussed below.

The change in yields is calculated as the difference between the actual yields in 21 different crop types (as recorded in the Census) and the predicted new yield given 85 percent of nitrogen. In our base scenario, we assume a 10 percent reduction in yields from the 15 percent reduction in nitrogen. In appendix I we show estimates using a 5 percent and 15 percent reduction in yields from a 15 percent reduction in nitrogen. Prices for crops were obtained largely from the National Agricultural Statistics Service. The values of corn silage, sorghum silage, and grass silage are calculated in relationship to the price of corn. In our "base" scenario we use prices from 2011; in appendix I we show estimates using prices from 2007, the year of the Census data to which we apply the model. See appendix G for more detail.

Fertilizer price comes from the Economic Research Service of the USDA; in our "base" scenario we use fertilizer prices from 2011 but show estimates in appendix I using prices for 2007. See appendix G for more detail. We estimate different manure shipping rates for dry versus wet manure and assume that poultry litter is dry and non-poultry manure is wet, following standard methods of manure management. We calculate the amount of wet or dry weight needed to be shipped off-farm from the amount of recoverable manure nitrogen to be reduced and the weight of manure generated. If a producer generates both poultry litter and non-poultry manure, we calculate

[19] Talberth and coauthors (2010a and 2010b) note that $20 assumes a fully-functioning post-TMDL nutrient credit market, rather than current prices. Due to the small number of trades that have occurred in the Chesapeake Bay states' individual nutrient trading programs, it is difficult to ascertain a past price for credits.

the unit shipping cost of each (in dollars per pound of nitrogen) and model the producer as reducing the cheaper type first. See appendix G for calculations of manure shipping prices and appendix H for methods for calculating the amount of manure versus fertilizer removed.

We apply the model to restricted-access 2007 Census of Agriculture data for Chesapeake Bay watershed counties (Chesapeake Bay Program 2008). We weight observations according to a weight supplied by the National Agricultural Statistics Service (NASS) to adjust for undercounting. While tables 1 and 2 show totals for land uses by farm type in the Chesapeake Bay, appendix table I1 provides averages of land uses across farms by operation type. The table shows, for example, that the average large CAFO has more crop acreage than the average "no livestock" farm with more than 100 acres of cropland. Small CAFOs are the most likely of the CAFOs to have crop and pasture acreage, and are also the most likely to have fertilized acreage and manure-applied acreage. Operations with non-confined livestock are the most likely to have pasture acreage. More summary statistics can be found in appendix tables I2-I5; these show that poultry constitute the largest percentage of animal units in the Chesapeake Bay counties, and that large and medium CAFOs are most likely to have poultry, while small CAFOs are most likely to have dairy cows. Additionally, CAFOs are more likely to grow alfalfa and other hay as well as corn for silage, and are also likely to have more acreage devoted to these crops.

We make a number of simplifying assumptions when applying the model. We first assume that producers that do not generate recoverable manure apply at least 15 percent of their nitrogen in the form of commercial fertilizer, and that any manure they apply is assumed free and generated off-farm.[20] We assume that producers that generate manure only apply fertilizer if they do not produce enough manure nitrogen to meet their agricultural fields' agronomic requirements. We make these assumptions as we have no way of identifying how much manure versus fertilizer is applied by each farmer (only the number of acres to which each is applied). See appendix F for more detail on assumptions about manure versus fertilizer application. We also assume that

[20]Because fertilizer reduction is cost-saving for these farms while manure reduction would not change costs, the crop-only farmer will reduce fertilizer first. Hence as long as the crop-only producer gets at least 15 percent of his nitrogen from fertilizer, then results will not change.

producers apply nitrogen in the form of either manure or fertilizer to reach the yields grown. This ignores producers who do not apply any fertilizer or manure. We assume that livestock producers meet the nutrient reduction only by shipping manure off-farm or reducing fertilizer use and not via any other method such as lowering the number of animals or altering feed.

Given this extensive set of assumptions, the results of applying the model to the data should be considered a comparison of entry into nutrient trading according to farm type rather a prediction of overall participation.

Simulation Results

Table 3 provides estimates of participation in and costs of ENM to generate nutrient credits for all agricultural operations in the Chesapeake Bay watershed counties. This table shows results from the "base" scenario with a credit price of $20 per pound of nitrogen reduced. We show average costs both for all possible participants in nutrient trading (those with an estimated non-zero nitrogen assimilative capacity) (top half of table 3) as well as for operations realizing a positive net value from participating in nutrient trading (bottom half of table 3). For example, table 4 shows that 94.5 percent of small CAFOs have non-zero nitrogen assimilative capacity; amongst these 94.5 percent of operations, the average small CAFO would realize a net benefit of *negative* $146,949 from participating in nutrient trading. As this is a negative number, the average small CAFO that is a possible participant would not enter nutrient trading. Only 5.3 percent of small CAFOs would realize a positive net value from nutrient trading (therefore finding it cost-beneficial). Of these 5.3 percent, the average small CAFO would realize $48,206 from nutrient trading.

Farms with more than 100 acres of cropland but no livestock are the most likely to find participation cost-beneficial (47.1 percent) and participating would generate the largest net value ($74,994). Smaller-scale crop-only producers (with less than 100 acres) and operations with non-confined livestock are similarly likely to find it cost-beneficial to participate (38.4 percent and 40.6 percent, respectively), but see much lower net values from doing so ($3,642 and $4,085, respectively).

Small and medium potential CAFOs are the least likely to find participation cost-beneficial in the base scenario (5.3 and 33.4 percent, respectively). In part this is due to the costs of meeting the NMP portion of the baseline. Small CAFOs, which are more likely to have dairy cows than other livestock types (appendix table I2), on average see a $14,921 cost of meeting the NMP baseline, much higher than the other types of farms. These small CAFOs also have higher average yield losses than large crop-only farms ($155,510 versus $144,566), despite having less crop acreage (see table 3). This largely arises from the high costs in terms of yield losses from alfalfa and other types of hay (see appendix table I6). Potential large CAFOs, which we assume have permits and already ship excess manure off-farm, are also less likely than crop-only farms to find participation cost-beneficial (36.4 percent). Relaxing this assumption (appendix tables I6 and I7) lowers predicted participation by large CAFOs, to 26.6 percent.

Changes in fertilizer and manure shipping costs are relatively small compared to the cost of changes in yields. Small and medium CAFOs save less in fertilizer expenses than large crop-only farms but more than small crop farms or pasture-based livestock operations when instituting ENM. While CAFOs pay more in manure export costs, these additional costs are on average very low. What appears to hurt CAFO participation the most is the loss in yields from reduced nitrogen use.

Appendix tables I6 and I7 shows six sensitivity analyses in comparison to the "base" scenario. In all sensitivity analyses, small CAFOs are the least likely to find participation in nutrient management cost-beneficial. For all farm types, more operations are likely to participate if yield losses are assumed to be only 5 percent, and fewer operations find participation cost-beneficial if yields losses are assumed to be 15 percent (versus the 10 percent in the "base" scenario). Other tests varying prices and certain assumptions cause little change in the estimates.

We also explore the effects of the nutrient credit price on the likelihood of participation by different types of farms. Appendix figure I1 shows the percentage of possible participants that find it cost-beneficial to engage in nutrient trading according to credit price. Between one and eight dollars per pound of nitrogen reduced, farms with non-confined livestock and small crop-only farms are the most likely to find participation cost-beneficial, although the amount they receive on average is very low (appendix figure I2). Between $8 and about $16 per pound of nitrogen reduced, participation for large crop-only farms jumps, and above a credit price of $16, large crop-only farms are the most likely to participate.

Conclusions and Policy Implications

Federal CWA CAFO rules interact with the structure of a Chesapeake Bay nutrient trading scheme in a complex manner. These complications would likely raise the costs to many livestock producers of participating in nutrient trading, which may increase the price of nutrient reduction credits and lessen the cost-effectiveness of the program in reducing water pollution. The effect on the credit price would depend on how much pollution the EPA hopes to reduce through nutrient trading and how many credits buyers demand.

Land-applied manure contributes approximately half of nutrient loadings to the Bay, and small and medium AFOs control nearly 60 percent of manure-applied acres in the watershed. If policy makers wish to reduce Bay nutrient pollution, then they may want to induce such operations to limit their discharges. Small and medium AFOs are often not regulated under CAFO rules, suggesting that alternate avenues are necessary to encourage them to mitigate run-off. One such avenue would be their participation in nutrient trading; as the operations would need to satisfy baselines requirements to enter trading, this would likely lower their discharges from pre-trading levels. However, we estimate that small and medium potential CAFOs are least likely to participate in trading, as the costs would outweigh the benefits. Further, such operations may avoid participation in a nutrient trading program based on fears of regulatory scrutiny. To reduce nutrient pollution from small and medium AFOs, policy-makers could increase the regulation stringency of such operations or subsidize their participation in nutrient trading.

This research highlights the importance of considering the entire farm rather than just the individual field when estimating participation in nutrient trading. Policy researchers assessing expected performance of nutrient trading often model a farmer's decision of whether to enroll a particular field in nutrient trading, without considering whole-farm-level practices that are precursors to participation. While we focus specifically on CAFO rules which only apply to livestock operations, other practices such as nutrient management plans are baseline requirements for all agricultural participants in Bay trading. We show that meeting these farm-level baseline requirements can have repercussions for whether nutrient trading participation is cost-beneficial. That is, the accuracy of predictions of nutrient trading's effect on reducing discharges as well as pollution control costs depend on farm-level in addition to field-specific effects.

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Table 1. Land use and nutrient application acres by type of agricultural operation, 2007

Operations with...	Number	Cropland Acres	Percentage of Cropland	Pastureland Acres	Percentage of Pastureland	Fertilized Acres	Percentage of Fertilized Acres	Manure-Applied Acres	Percentage of Manure-Applied Acres
All	**108,176**	**8,750,192**	**100.0%**	**3,825,968**	**100.0%**	**5,886,001**	**100.0%**	**2,190,379**	**100.0%**
No livestock -- Less than 100 acres of cropland	30,531	760,001	8.7%	489,280	12.8%	250,834	4.3%	54,814	2.5%
No livestock -- 100 or more acres of cropland	5,878	2,467,704	28.2%	123,993	3.2%	1,887,633	32.1%	197,455	9.0%
Some livestock but not likely to be confined	55,834	2,407,351	27.5%	2,476,526	64.7%	1,522,821	25.9%	500,403	22.8%
Potential Small CAFOs	12,528	2,072,888	23.7%	527,133	13.8%	1,423,142	24.2%	904,815	41.3%
Potential Medium CAFOs	2,826	769,160	8.8%	169,800	4.4%	595,553	10.1%	393,827	18.0%
Potential Large CAFOs	579	273,088	3.1%	39,236	1.0%	206,018	3.5%	139,065	6.3%

Table 2. Estimated nitrogen generation and uptake, Chesapeake Bay farms, 2007

	All Farms				By Farm	
Type of Farm	**Assimilative Capacity (lbs N)**	**Percentage of Assimilative Capacity**	**Recoverable Nitrogen Produced (lbs N)**	**Percentage of Recoverable Nitrogen Produced**	**Average Assimilative Capacity (lbs N)**	**Average Recoverable Nitrogen Produced (lbs N)**
All	1,082,586,756	100.0%	894,954,160	100.0%	11,954	8,764
No livestock -- Less than 100 acres of cropland	53,599,777	5.0%	0	0.0%	2,965	0
No livestock -- 100 or more acres of cropland	311,618,093	28.8%	0	0.0%	62,125	0
Some livestock but not likely to be confined	298,232,432	27.5%	0	0.0%	5,633	0
Potential Small CAFOs	279,567,722	25.8%	704,360,631	78.7%	23,620	54,167
Potential Medium CAFOs	102,717,348	9.5%	95,003,445	10.6%	45,632	31,048
Potential Large CAFOs	36,851,383	3.4%	95,590,084	10.7%	83,753	187,934

Note: Nitrogen uptake capacity refers to 23 different crop and pasture categories; see text for more detail.

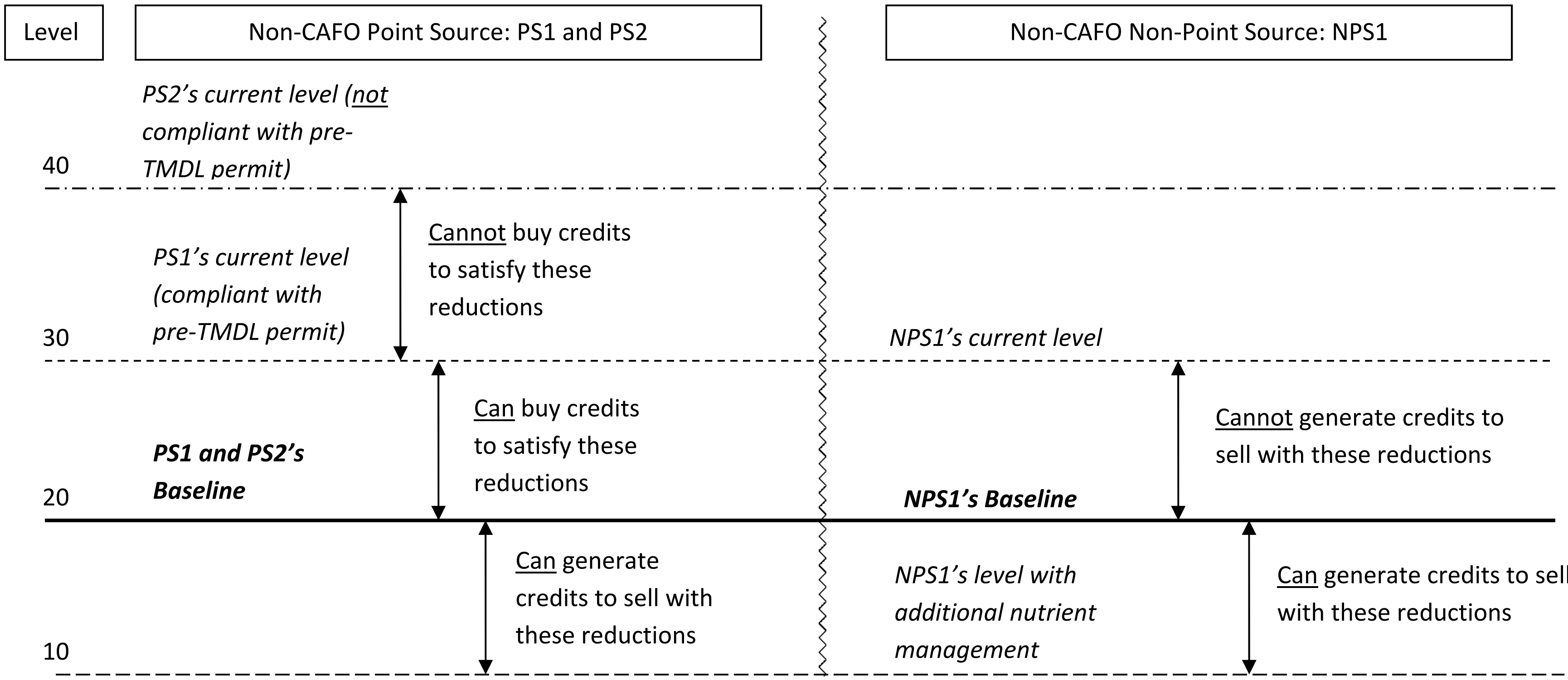
Table 3. Predicted participation in enhanced nutrient management to generate nutrient credits, by type of agricultural operation

Type of Farm	Percentage that are possible participants	Of all possible participants: Average net value of credits	Average benefit from nutrient credits	Average cost of meeting baseline BMPs other than NMP	Average cost of meeting baseline NMP	Average cost of change in yields	Average change in fertilizer costs	Average change in manure shipping costs to generate credits
All	**83.7%**	**-44,361**	**17,931**	**913**	**2,031**	**59,840**	**-805**	**6**
No livestock -- Less than 100 acres of cropland	59.2%	-14,101	4,447	277	83	18,390	-203	0
No livestock -- 100 or more acres of cropland	85.3%	-53,037	93,187	4,550	1,365	144,566	-4,256	0
Some livestock but not likely to be confined	94.8%	-28,352	8,450	450	135	36,603	-386	0
Potential Small CAFOs	94.5%	-146,949	35,430	1,747	14,921	155,510	-1,576	19
Potential Medium CAFOs	79.7%	-141,927	68,448	3,406	3,335	199,418	-2,932	85
Potential Large CAFOs -- With prior regulation	76.0%	-181,503	125,630	6,181	0	305,565	-4,936	323

Type of Farm	Percentage of possible participants finding it cost-beneficial to participate	Of farms finding it cost-beneficial to participate: Average net value of credits	Average benefit from nutrient credits	Average cost of meeting baseline BMPs other than NMP	Average cost of meeting baseline NMP	Average cost of change in yields	Average change in fertilizer costs	Average change in manure shipping costs to generate credits
All	**35.7%**	**10,595**	**18,781**	**726**	**213**	**8,098**	**-853**	**2**
No livestock -- Less than 100 acres of cropland	38.4%	3,642	4,899	172	51	1,257	-224	0
No livestock -- 100 or more acres of cropland	47.1%	74,994	145,315	6,203	1,861	68,893	-6,637	0
Some livestock but not likely to be confined	40.6%	4,085	5,689	143	43	1,678	-260	0
Potential Small CAFOs	5.3%	48,206	78,489	2,510	766	30,582	-3,578	3
Potential Medium CAFOs	33.4%	21,076	55,419	2,867	969	32,946	-2,466	28
Potential Large CAFOs -- With prior regulation	36.4%	39,259	104,818	5,131	0	64,424	-4,236	241

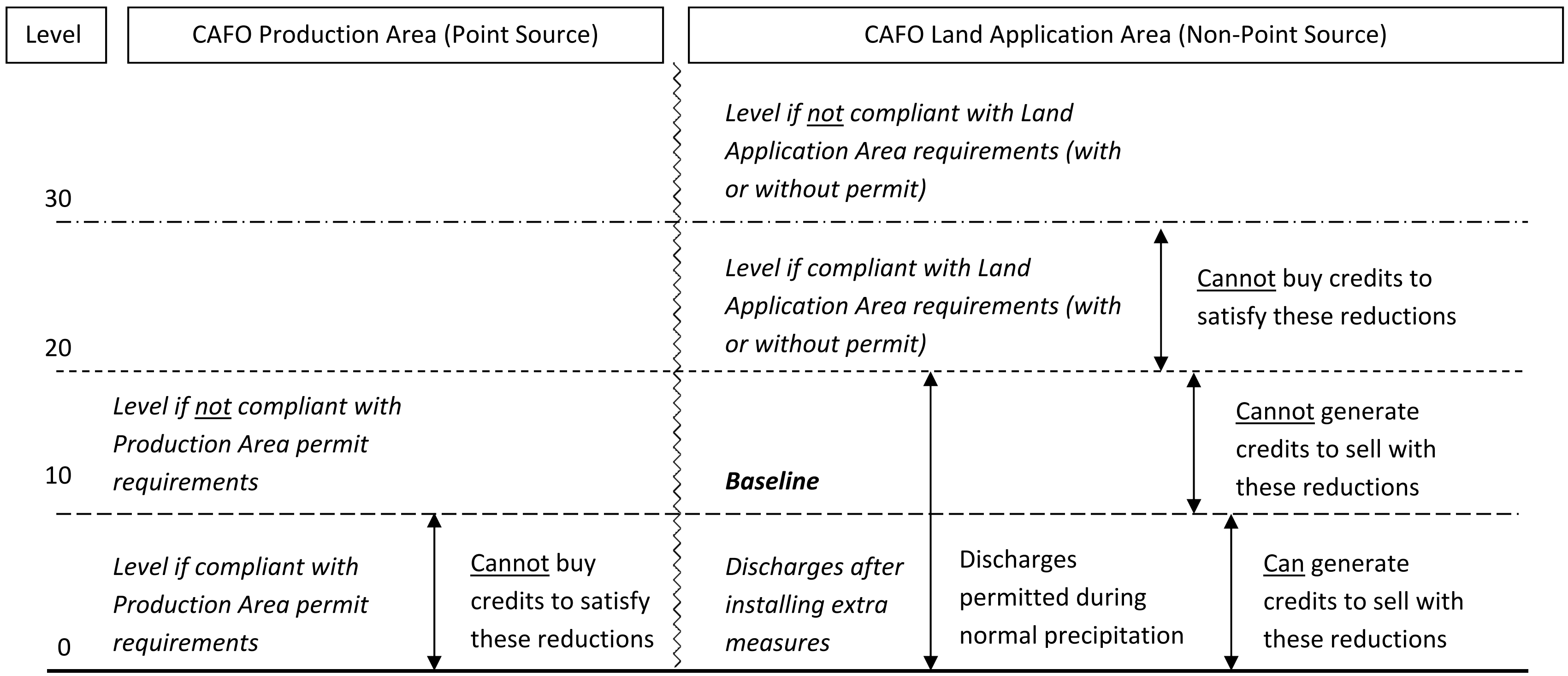
Notes: Assumes a value of nutrient credits of $20/lb. Possible participants include just those farms with non-zero nitrogen uptake capacity in at least one of 23 different crop and pasture categories.

Figure 1: Pollution load levels pertinent for nutrient trading by non-CAFO point and non-point sources



Notes: Level describes discharge load. Numbers are for expository purposes. See text for further description.

Figure 2. Pollution load levels pertinent for nutrient trading, CAFO production and land application areas



Notes: Level describes discharge load. Numbers are for expository purposes. See text for further description.

Appendices for

"Differences between Livestock and Crop Producers' Participation in Nutrient Trading"

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Appendix A: Details on CWA CAFO Regulations and Nutrient Trading Program Rules

Clean Water Act CAFO Rules

Production Area Rules

The production area must be "properly designed, constructed, operated, and maintained to contain all manure, litter, process wastewater and the runoff and direct precipitation from the 25-year, 24-hour storm event for the location of the CAFO" (EPA 2003, p. J-8). This is the production area "technology-based effluent limitation" (TBEL) guideline for large CAFOs; the requirements for small- and medium-sized CAFOs depend on the permit writer's "best professional judgment." A "25-year, 24-hour storm event" is calculated by the National Weather Service as the maximum possible precipitation in a 24-hour period that has the likelihood of occurring once every 25 years. New facilities must be able to accommodate a 100-year 24-hour storm in addition to their normal waste volumes.

Land Application Area Rules

The federal CAFO permit requires the implementation of a Nutrient Management Plan (NMP) that follows specific guidelines, including the determination of application rates that minimize nutrient run-off, manure and soil sampling, periodic inspection of land application equipment, and set-back requirements (EPA 2003, p. J-9). These are the stipulations in the land application area TBEL guidelines for large CAFOs. Requirements on the land application areas of small- and medium-sized CAFOs are based on the permit writer's "best professional judgment."

Additional CAFO Rules Under the Chesapeake Bay TMDL

The federal NPDES CAFO permit also allows for additional stipulations on the production area in the event that a water body is not reaching its desired quality level even when the dischargers to it are abiding by their permits. Additional stipulations are included in an individual permit depending on the specific water bodies to which the permitted entity discharges. These additional stipulations are called "water quality based effluent limitation" (WQBEL) guidelines. There are no additional stipulations for either the production or land application areas of CAFOs under the Chesapeake Bay TMDL

Appendix Table A1: Size Thresholds for CAFO Regulations

	Small	Medium	Large
Cattle (other than mature dairy cows)[a]	Less than 300	300 to 999	At least 1,000
Mature dairy cows	Less than 200	200 to 699	At least 700
Swine (55 pounds or more)	Less than 750	750 to 2,499	At least 2,500
Swine (less than 55 pounds)	Less than 3,000	3,000 to 9,999	At least 10,000
Horses	Less than 150	150 to 499	At least 500
Sheep or lambs	Less than 3,000	3,000 to 9,999	At least 10,000
Turkeys	Less than 16,500	16,500 to 54,999	At least 55,000
Chickens (liquid manure handling system)	Less than 9,000	9,000 to 29,999	At least 30,000
Laying hens (no liquid manure handling system)	Less than 25,000	25,000 to 81,999	At least 82,000
Chickens other than laying hens (no liquid manure handling system)	Less than 37,500	37,500 to 124,999	At least 125,000
Ducks (liquid manure handling system)	Less than 1,500	1,500 to 4,999	At least 5,000
Ducks (no liquid manure handling system)	Less than 10,000	10,000 to 29,999	At least 30,000

[a]Refers to cattle, dairy heifers, cow/calf pairs, or veal calves.

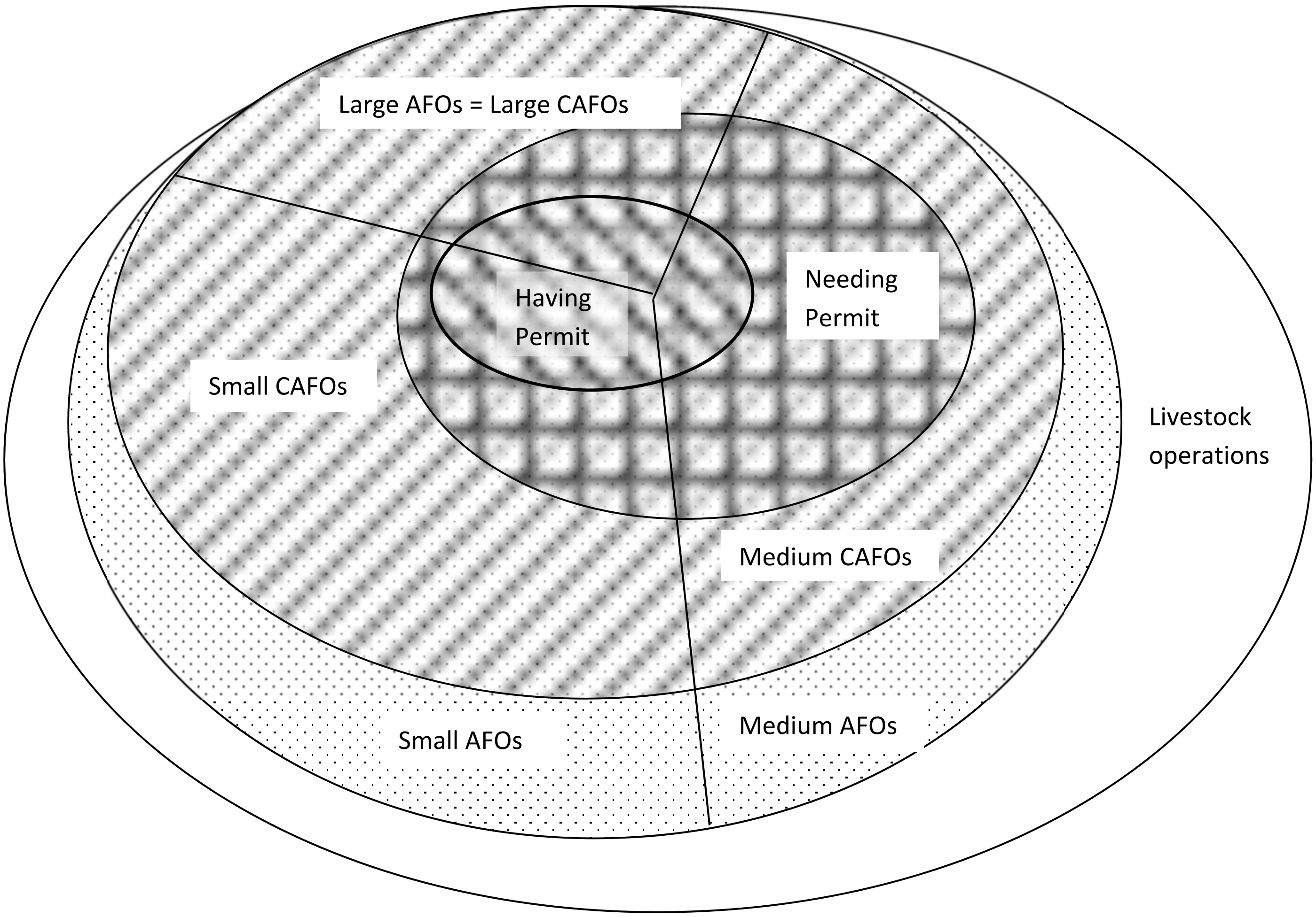
Source: EPA 2003

Appendix Table A2: Permit requirements for land application areas of CAFOs compared to practices required for agricultural non-point sources to meet "baseline" in nutrient trading programs

		Permit requirements for Large CAFOs	
Federal		• Production area is properly designed, constructed, and operated to contain all manure, litter, process wastewater and the runoff and direct precipitation from a 25-year, 24-hour storm event • Implement NMP • Implement manure and soil testing. • Prevent direct contact of confined animals with waters of the U.S. • Record keeping. • One of the following: 1. Implement 100-foot setback for manure application from waters of the U.S. 2. Implement a 35-foot vegetative buffer.	
State		**Permit requirements for Large CAFOs**	**Baseline requirements for agricultural non-point sources**
	Maryland	• All federal stipulations • Soil and water quality conservation plan • Alternatives to 100-foot setback or 35-foot vegetative buffer	• Achieve reduced per-acre nutrient loading rates according to TMDL specifications. • Comply with all applicable regulations • Implement NMP • Implement soil and water conservation plan and waste management system plan
	Pennsylvania	• All federal stipulations • Erosion and sediment control plan for acreage that is plowed or tilled • Implement NMP according to phosphorus standard	• Comply with all applicable regulations • Do one of the following: 1. Implement 100-foot setback for manure application. 2. Implement a 35-foot vegetative buffer. 3. Reduce operation's total nutrient balance by 20% below reductions achieved through regulations.
	Virginia	• All federal stipulations • Compliance with local zoning ordinances • Implement NMP according to phosphorus standard • Groundwater monitoring • Implement set-back of 200-feet from occupied dwellings not on owner's property • Implement 100-foot buffer zone from water supply wells or springs	• Comply with all applicable regulations • Implement soil conservation plan. • Implement NMP. • Plant winter cover crops. • Fence waterways so that livestock do not enter them. • Implement a 35-foot vegetative buffer.
	West Virginia	• All federal stipulations	• Comply with all applicable regulations • Achieve Tributary Strategies per-acre loading rates. • Implement whole-farm NMP.

Notes: There currently is no federal or Chesapeake Bay-wide nutrient trading program. Delaware and New York are also in the Chesapeake Bay watershed but have not yet implemented state-level nutrient trading programs. Information on baseline requirements from Branosky, Jones, and Selmen 2011, p.9, and Latane and Stephenson 2011. Information on federal permit from EPA 2003. Information for state CAFO permit requirements comes from the following: Maryland: MDDE 2009, MDDE 2010; Pennsylvania: Commonwealth of Pennsylvania 2006; Virginia: Virginia Administrative Code 9VAC 25-192-70; West Virginia: NASDA 2000, WVDEP 2010.

Appendix Fig.A1:
Relationship Between Types of Livestock Operations According to Regulatory Category



Appendix B: Calculating Animal Units and Confinement

The NRCS methodology used throughout the appendices is described in Kellogg *et al* (2000) (hereafter KLMG) and Kellogg, Moffitt, and Gollehon (2012) (hereafter KMG). KMG serves as an update to KLMG, containing revised parameters and certain changes in methodology.

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. 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. Hence 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. Further, we normalize across animal types by converting head to "animal units" (AUs). 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 AU algorithm is:

(B1) $annual\ average\ AU =$

$$\left\{\left(inventory \times \frac{1}{cycles}\right) + \left[\frac{sales}{cycles} \times \frac{(cycles - 1)}{cycles}\right]\right\} \times \left(\frac{1}{animals\ per\ AU}\right)$$

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

(B2) $annual\ average\ AU = \left(inventory \times \frac{1}{2} \times \frac{1}{cycles}\right) \times \left(\frac{1}{animals\ per\ AU}\right)$

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

(B3) $annual\ average\ AU = \left(\frac{sales}{cycles}\right) \times \frac{1}{animals\ per\ AU}$

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 algorithm to estimate the number of AUs is:

(B4) $annual\ average\ AU = \frac{inventory}{animals\ per\ AU}$

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 below.

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. For example, the equation to estimate the number of AUs in the farm's hogs for breeding is listed in KLMG as:

(B5) $$AU = \frac{breeding\ hog\ inventory}{2.67}$$

Where 2.67 refers to the number of animal units per head of breeding hog. KMG have updated this parameter for the number of animal units per head of breeding hog in the 2007 Census of Agriculture to be 2.27 (p. 5, Table 1). Thus for 2007 we estimate the number of AUs in the farm's hogs for breeding as:

(B6) $$AU = \frac{breeding\ hog\ inventory}{2.27}.$$

Appendix Table B1 lists the livestock categories for which we follow precisely the equations in KLMG or equations B1-B4 except for updating the parameters according to KMG.

For the livestock categories not listed in Appendix Table B1, 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 below.

Fattened cattle

The equations for fattened cattle in KLMG are based on sales data, which was 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 in the 2002 and 2007, thus we use equations B1-B3 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.

(B7) 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

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

(B8) 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

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

(B9) 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 less than 500 pounds. To do this, we first find farms without any dairy or beef cattle in inventory but with sales of cattle less than 500 pounds. We calculate the potential number of veal AUs these sales would represent according to the following equation:

(B10) $Potential\ Veal\ AUs = (Number\ of\ cattle\ less\ than\ 500lbs.sold) \times \frac{3.5}{12} \times \frac{1}{4.4}$

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 B10). 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 in Appendix C.

Confined portion of pastured livestock types

Following KMG, we characterize livestock types as "confined" and "pastured." These types are listed in Appendix Table B2. A portion of the pasture-type livestock are also assumed to be confined according to the ratio of animal units to the amount of pastureland available on the operation.

Appendix Table B1: 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	B4
Hogs for breeding	eq. 7	Year-end inventory	B4
Hogs for slaughter – Farrow to wean		Year-end inventory and sales	B1-B3
Hogs for slaughter – Farrow to finish		Year-end inventory and sales	B1-B3
Hogs for slaughter – Finish only		Year-end inventory and sales	B1-B3
Hogs for slaughter – Farrow to feeder		Year-end inventory and sales	B1-B3
Hogs for slaughter – Nursery		Year-end inventory and sales	B1-B3
Breeding turkeys	eq. 13-14	Year-end inventory and sales	B1-B3
Slaughter turkeys	eq. 21-23	Year-end inventory and sales	B1-B3
Chicken broilers	eq. 18-20	Year-end inventory and sales	B1-B3
Chicken pullets		Year-end inventory and sales	B1-B3
Ducks		Year-end inventory and sales	B1-B3
Horses and ponies		Year-end inventory	B4
Mules, burros, and donkeys		Year-end inventory	B4
Sheep and goats		Year-end inventory	B4
Bison		Year-end inventory	B4
Deer		Year-end inventory	B4
Elk		Year-end inventory	B4
Llama		Year-end inventory	B4
Mink		Year-end inventory	B4
Rabbits		Year-end inventory	B2
Emu		Year-end inventory	B4
Geese		Year-end inventory	B2
Ostriches		Year-end inventory	B4
Pheasants		Year-end inventory	B2
Pigeons		Year-end inventory	B2
Quail		Year-end inventory	B2

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 (2012).

Appendix Table B2: Livestock Types, as Characterized by KM

Confined livestock types	Pastured livestock types	Specialty livestock types
• Fattened cattle	• Horses and ponies	• Bison
• Veal calves	• Mules, burros, and donkeys	• Deer
• Milk cows	• Sheep and goats	• 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		• Pigeons
• Chicken layers		• Quail
• Chicken broilers		
• Chicken pullets		
• Ducks		

Appendix C: Equations for Calculating Pastured Beef and Dairy Animal Units

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

(C1) $Bulls = \min\{(0.05 \times Beef\ cow\ inventory), \max[0, (Other\ cattle\ inventory - Fattened\ cattle)]\}$

(C2) $Beef\ cow\ breeding\ herd\ head = Beef\ cow\ inventory + Bulls$

(C3) $Beef\ cow\ breeding\ herd\ AU = Beef\ cow\ breeding\ herd\ head$

(C4) $Expected\ beef\ calves = \min\{(beef\ cow\ inventory\ \times 0.82), \max[0, (Other\ cattle\ inventory - Fattened\ cattle - Bulls)]\}$

Where 0.82 is the calving rate from KMG.

(C5) If $(Expected\ beef\ calves \leq Number\ of\ cattle\ less\ than\ 500 lbs\ sold)$ then

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

(C6) If $(Expected\ beef\ calves > Number\ of\ cattle\ less\ than\ 500 lbs\ sold)$ or $(Number\ of\ cattle\ less\ than\ 500 lbs\ sold = 0)$ then

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

(C7) $Beef\ calves\ head =$

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

(C8) $Beef\ calves\ AU = \frac{Beef\ calves\ head}{4}$

(C9) $Beef\ replacement\ herd\ heifers = \min\{(0.15 \times beef\ cow\ inventory),$

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

$-Bulls)]\}$

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

(C10) $Beef\ replacement\ herd\ heifer\ head = Beef\ replacement\ herd\ heifers\ \times \frac{5}{12}$

(C11) $Beef\ replacement\ herd\ heifer\ AU = \frac{(Beef\ replacement\ herd\ heifers\ head)}{1.14}$

(C12) $Beef\ stockers\ sold =$

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

(C13) $Beef\ stockers\ inventory =$

$\max\{0, [Other\ cattle\ inventory - Beef\ replacement\ herd\ heifers\ head$

$-Bulls - Expected\ beef\ calves\ - Fatted\ cattle]\}$

(C14) $Beef\ stockers\ head = \frac{Beef\ stockers\ inventory}{2} + \frac{Beef\ stockers\ sold}{4}$

(C15) $Beef\ stockers\ AU = \frac{Beef\ stockers\ head}{1.73}$

<u>For farms with dairy cows but no beef cattle in inventory:</u>

(C16) $Expected\ dairy\ calves = \min\{(dairy\ cow\ inventory\ \times 0.65),$

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

Where 0.65 is the calving rate from KMG.

(C17) If $(Expected\ dairy\ calves \leq Number\ of\ cattle\ less\ than\ 500 lbs.sold)$ then

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

$(\ Number\ of\ cattle\ less\ than\ 500 lbs.sold) -\ (Expected\ dairy\ calves)$

(C18) If $(Expected\ dairy\ calves > Number\ of\ cattle\ less\ than\ 500lbs.sold)$ or

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

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

(C19) $Dairy\ calves\ head =$

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

(C20) $Dairy\ calves\ AU = \frac{Dairy\ calves\ head}{4}$

(C21) $Dairy\ replacement\ herd\ heifers =$

$\min\{(0.2 \times Dairy\ cow\ inventory),$

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

$-Fattened\ cattle)]\}$

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

(C22) $Dairy\ replacement\ herd\ heifers\ head$

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

(C23) $Dairy\ replacement\ herd\ heifers\ AU = \frac{(Dairy\ replacement\ herd\ heifers\ head)}{1.04}$

(C24) $Dairy\ stockers\ sold =$

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

(C25) $Dairy\ stockers\ inventory =$

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

$-Dairy\ heifer\ head\ - Fattened\ cattle)]$

(C26) $Dairy\ stockers\ head = \frac{Dairy\ stocker\ inventory}{2} + \frac{Dairy\ stockers\ sold}{4}$

(C27) $Dairy\ stockers\ AU = \frac{Dairy\ stockers\ head}{1.73}$

<u>For farms with both dairy cows and beef cattle in inventory:</u>

(C28) $Bulls = \min\{(0.05 \times Beef\ cow\ inventory),$
$\max[0, (Other\ cattle\ inventory - Fattened\ cattle)]\}$

(C29) $Beef\ cow\ breeding\ herd\ head = beef\ cow\ inventory + bulls$

(C30) $Beef\ cow\ breeding\ herd\ AU = Beef\ cow\ breeding\ herd$

(C31) $Expected\ dairy\ calves =$
$\min\{(Dairy\ cow\ inventory\ \times 0.65), \max[0, (Other\ cattle\ inventory -$
$Bulls - Fattened\ cattle)]\}$

(C32) $Dairy\ calves\ head =$
$$\left[\left(Expected\ dairy\ calves \times \frac{5}{12}\right) + \left(Purchased\ and\ sold\ dairy\ calves \times \frac{2.5}{12}\right)\right]$$

(C33) $Dairy\ calves\ AU = \frac{Dairy\ calves\ head}{4}$

(C34) $Expected\ beef\ calves =$
$\min\{(Beef\ cow\ inventory\ \times 0.82), \max[0, (Other\ cattle\ inventory$
$-Fattened\ cattle - Bulls - Expected\ dairy\ calves)]\}$

(C35) If $[(Expected\ beef\ calves + expected\ dairy\ calves) \leq$

$Number\ of\ cattle\ less\ than\ 500lbs.sold]$ then

$Purchased\ and\ sold\ beef\ calves$

$= (\ Number\ of\ cattle\ less\ than\ 500lbs.sold)$

$- (Expected\ beef\ calves) - (Expected\ dairy\ calves)$

(C36) If $[(Expected\ beef\ calves + Expected\ dairy\ calves) >$

$Number\ of\ cattle\ less\ than\ 500lbs.sold]$ or

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

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

(C37) $Beef\ calves\ head =$

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

(C38) $Beef\ calves\ AU = \frac{Beef\ calves\ head}{4}$

(C39) $Dairy\ replacement\ herd\ heifer\ inventory =$

$\min\{(0.2 \times Dairy\ cow\ inventory), \max[0, (Other\ cattle\ inventory$

$-Fattened\ cattle - Bulls - Expected\ dairy\ calves$

$-Expected\ beef\ calves)]\}$

(C40) $Dairy\ replacement\ herd\ heifers\ head$

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

(C41) $Dairy\ replacement\ herd\ heifers\ AU = \frac{(Dairy\ replacement\ herd\ heifers\ head)}{1.04}$

(C42) $Beef\ replacement\ herd\ heifer\ inventory =$

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

(C43) $Beef\ replacement\ herd\ heifer\ head =$

$$Beef\ replacement\ herd\ heifer\ inventory\ \times \frac{5}{12}$$

(C44) $Beef\ replacement\ herd\ heifer\ AU = \frac{(Beef\ replacement\ herd\ heifers\ head)}{1.14}$

(C45) $Beef\ stockers\ sold =$

$$\max\{0, [(Cattle\ more\ than\ 500\ pounds\ sold) - (fattened\ cattle\ sold)]\}$$

(C46) $Beef\ stockers\ inventory =$

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

(C47) $Beef\ stockers\ head = \frac{Beef\ stockers\ inventory}{2} + \frac{Beef\ stockers\ sold}{4}$

(C48) $Beef\ stockers\ AU = \frac{Beef\ stockers\ head}{1.73}$

(C49) $Dairy\ stockers\ sold =$

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

(C50) $Dairy\ stockers\ inventory =$

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

(C51) $Dairy\ stockers\ head = \frac{Dairy\ stocker\ inventory}{2} + \frac{Dairy\ stockers\ sold}{4}$

(C52) $Dairy\ stockers\ AU = \frac{Dairy\ stockers\ head}{1.73}$

<u>For farms with no beef or milk cows but with sales of cattle less than 500 pounds but that are not veal farms:</u>

(C53) $Beef\ calves\ head = Sales\ of\ cattle\ less\ than\ 500\ lbs \times \frac{3.5}{12}$

And

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

Appendix D: Calculation of Recovered Elemental Nitrogen in Recovered Manure or Litter

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), using the following equation:

(D1) $$DW = \sum_j [(Number\ of\ AUs)_j \times (Tons\ of\ manure\ per\ AU\ per\ year\ in\ oven - dry\ weight)_j]$$

In equation (D1), j indexes the animal type. 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.

Next we calculate the wet weight of manure as excreted. The tons of wet weight of manure as excreted (WW) at each operation is calculated as:

(D2) $$WW = \sum_j [(Number\ of\ AUs\ )_j \times (Tons\ of\ wet\ weight\ manure\ per\ AU\ per\ year)_j]$$

Again, j indexes the animal type. The parameters for the tons of wet weight manure per AU per year are from KMG and differ by animal type. For later estimates of manure shipping costs we also calculate the wet weight of manure for poultry (WW^B) and other livestock types (WW^C).

Following KMG, we assume that the only manure that can be “recovered” can be spread on fields or shipped off farm. Using the amount of wet weight manure as excreted, we use additional parameters to estimate the amount of excreted manure that can be recovered (in tons), the amount of nitrogen in the recovered excreted manure (in pounds), and the amount of *recovered* elemental nitrogen in the *recovered* excreted manure (N_M, in pounds):

(D3) $Wet\ weight\ of\ recoverable\ manure\ (tons)_j =$

$(Wet\ weight\ of\ manure\ as\ excreted\ )_j \times (Manure\ recoverability\ factor)_j$

(D4) $Nitrogen\ in\ recoverable\ manure\ (pounds)_j =$

$(Wet\ weight\ of\ recoverable\ manure)\ _j$

$\times (Pounds\ of\ nitrogen\ per\ ton\ of\ wet\ weight)_j$

(D5) $N_M = \sum_j [(Nitrogen\ in\ recoverable\ manure\ )_j \times$

$(Proportion\ of\ nutrients\ retained\ in\ recoverable\ manure)_j]$

The manure recoverability factors, pounds of nitrogen per ton of wet weight, and proportion of nutrients retained in recoverable manure are found in KMG. Wet weight manure per AU per year and pounds of nitrogen per ton of wet weight vary according to animal type; for pastured livestock types different factors are used for the pastured and confined portions. The proportion of nutrients retained in recoverable manure also varies according to animal type. Manure recoverability factors vary according to livestock type, region, and size class. Additionally, these vary according 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 the scenario described in KMG as “after CNMP”; these are the manure recoverability factors from 2017 in KMG. The proportion of nutrients not retained in recoverable manure is lost in transportation and to the atmosphere.

For later use in calculating manure shipping costs, we also calculate the amount of recovered elemental nitrogen in recovered poultry litter (N_M^B) versus that in the manure of other livestock types (N_M^C).

Appendix E: Calculation of Nitrogen Used by Crops and Pastureland

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

Harvested cropland

We estimate the amount of nitrogen that can be absorbed 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 nitrogen used on the crop (N_U) at an individual operation is estimated according to the following equation:

(E1) $N_U = \sum_k [(Yield)_k \times (Nitrogen\ per\ yield\ unit)_k]$

Here, k indexes the crop type at the individual operation. The pounds of nitrogen 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 E1 lists the 21 crops for which we estimate the amount of nitrogen assimilative capacity on harvested cropland.

Appendix Table E1:

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

Cropland used as pasture and permanent pasture

Since no crops are harvested on cropland used as pasture and pastureland, we cannot calculate nitrogen uptake from this land type. We therefore follow KMG and assume that 75 pounds of nitrogen can be applied per acre of cropland used as pasture and that 30 pounds of nitrogen can be applied per acre of permanent pastureland.

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.

Appendix F: Calculation of Amount of Nitrogen Applied

The nitrogen uptake capacity represents the amount that crops use; however, crops will only use a portion of the nitrogen applied. In order to obtain the yields recorded, the farmer must apply more nitrogen than the amount used. An application-removal ratio greater than one multiplied by the amount of nitrogen used will provide an estimate of the amount needed for recorded yields. We use an application-removal ratio of 1.2, which represents an 83 percent absorption rate; this means that 83 percent of the elemental nitrogen applied will be used by crops. KMG note that the application ratio of 1.2 has been used in prior National Resource Conservation Service (NRCS) studies to imply full nutrient management and soil erosion control practices. The amount of elemental nitrogen needed for recorded yields (N_A) is therefore:

(F1) $N_A = 1.2N_U$

We also perform our analyses with a crop application-removal ratio of 1.4, which represents a 71 percent efficiency in crop uptake and removal of nitrogen. KMG note that this ratio is "an acceptable rate of application when nitrogen losses are not well controlled by conservation practices" (p. 19). Results from this sensitivity analysis can be found in Appendix I.

In Appendix D we described how we calculate the amount of recovered elemental nitrogen in recoverable manure. In the process we adjust for the fact that only a portion of manure is nitrogen, and that only a portion of that nitrogen can be used by crops. We assume that the recovered elemental nitrogen in recoverable manure is as readily available for crop uptake as the elemental nitrogen in commercial fertilizer.

We make three assumptions about how much nitrogen is actually applied based on how much manure is produced on the operation:

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 a farmer produces more recoverable manure nitrogen than is needed for agricultural fields, 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 ($N_F = N_A - N_M$).

Note that by assumption, the only operations that over-apply nitrogen are farms with recoverable manure nitrogen.

Appendix G: Model Parameters

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 G1: Commodity Prices Used in Simulation

Commodity	**Price per unit, 2007**	**Price per unit, 2011**	**Source and/or assumptions**
Corn for grain (bu)	$4.00	$6.20	NASS (2008), NASS (2012)
Corn for silage (ton)	$29.43	$45.61	Set at (27/3.67) the price of corn for grain; calculates the grain content of the corn silage; Snyder (2011).
Soybeans (bu)	$10.40	$11.70	NASS (2008), NASS (2012)
Sorghum for grain (cwt)	$6.95	$10.90	NASS (2008), NASS (2012); converted to price per bushel by using 100lbs = 1 cwt and 56 bu = 1 lb.
Sorghum for silage (ton)	$26.49	$41.05	Set at 90% of the corn silage price; Guyer and Duey (1974).
Cotton (lint and seed) (lb)	$0.569	$0.965	NASS (2008) , NASS (2012); converted to price per bale by multiplying by 480 (for 480 lb per bale).
Barley (bu)	$4.10	$5.40	NASS (2008), NASS (2012)
Winter wheat (bu)	$6.65	$6.85	NASS (2008), NASS (2012)
Durum wheat (bu)	$9.75	$9.90	NASS (2008), NASS (2012)
Other spring wheat (bu)	$6.90	$8.30	NASS (2008), NASS (2012)
Oats (bu)	$2.50	$3.40	NASS (2008), NASS (2012)
Rye for grain (bu)	$4.96	$7.77	NASS (2008), NASS (2012)
Rice (cwt)	$11.50	$14.20	NASS (2008), NASS (2012)
Peanuts for nuts (lb)	$0.204	$0.280	NASS (2008), NASS (2012)
Sugar beets for sugar (ton)	$44.80	$66.70	NASS (2008), NASS (2012)
Tobacco (lb)	$1.683	$1.867	NASS (2008), NASS (2012)
Alfalfa hay (ton)	$138.00	$196.00	NASS (2008), NASS (2012)
Small grain hay (ton)	$120.00	$125.00	NASS (2008), NASS (2012)
Other tame hay (ton)	$120.00	$125.00	NASS (2008), NASS (2012)
Wild hay, including sorghum hay (ton)	$120.00	$125.00	NASS (2008), NASS (2012)
Grass silage (ton)	$25.62	$39.70	Set at (22.85/26.25) the corn silage price. Staples (1995).

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. Anhydrous ammonia sold for $523/ton in 2007 and $749/ton in 2011 (ERS, 2012). We therefore convert from pounds to tons by dividing by 2,000. P_F is the price per pound of elemental nitrogen in anhydrous fertilizer:

(G1) $$P_F = \frac{1}{0.82} \times Price\ per\ ton\ of\ anhydrous\ fertilizer \times \frac{1}{2000}$$

The amount saved by reducing fertilizer is therefore:

(G2) $$Cost\ of\ fertilizer\ change = \Delta N_F \times P_F$$

Where ΔN_F is the change in nitrogen in fertilizer due to instituting enhanced nutrient management in pursuit of generating credits.

Manure shipping price

We allow different shipping costs according to whether the nitrogen in the manure arises from poultry or other livestock types. 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 find hauling costs of $2 per ton as a base charge plus $0.30 per mile when shipping off-farm (p. 61). For dry litter systems, they find a $10 per ton base charge and a $0.11 per mile charge when shipping more than 2 miles from the farm (p. 61). The average county in the Chesapeake Bay watershed is approximately 478 square miles (calculated from the total area per county recorded in the Area Resource File, 2003). Using this metric we assume that a farmer will need to ship manure 11 miles in our "base" scenario and 31 miles as a high estimate. In summary, the prices per ton to ship dry and wet weight manure are assumed to have the following values:

Appendix Table G2: Manure Shipping Prices Used in Simulation

Variable	**Description**	**Base Scenario Estimate** (11 miles)	**High Estimate** (31 miles)
P_{DW}	Shipping price per ton of dry weight manure or litter	$11.21	$13.41
P_{WW}	Shipping price per ton of wet weight manure or litter	$5.30	$11.30

We show results from using the high estimates of shipping costs in Appendix I.

In Appendix I 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 in manure in pounds per ton of wet weight. To convert changes in pounds of nitrogen 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 per ton of wet weight manure (N_M^C):

(G3) $$\Delta N_M^C \times \frac{WW^C}{N_M^C} = Change\ in\ tons\ of\ wet\ weight\ non-poultry\ manure$$

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:

(G4) $$P_{WW} \times (Change\ in\ tons\ of\ wet\ weight\ non-poultry\ manure)$$

$$= Cost\ of\ reducing\ non-poultry\ manure$$

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

(G5) $$P_M^C = \frac{WW^C}{N_M^C} \times P_{WW}$$

Like we do for non-poultry manure, we estimate the change in (elemental) nitrogen in poultry litter as excreted in pounds per ton of wet weight (described in Appendix H). To convert changes in pounds of nitrogen 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 per ton of wet weight litter (N_M^B).

(G6) $$\Delta N_M^B \times \frac{DW^B}{WW^B} = Change\ in\ tons\ of\ dry\ weight\ poultry\ litter$$

This gives us the change in dry wet poultry litter needed to reduce the elemental nitrogen by the amount required by enhanced nutrient management.

The total cost of reducing poultry litter is therefore:

(G7) $$P_{DW} \times (Change\ in\ tons\ of\ dry\ weight\ poultry\ litter) =$$

$$Cost\ of\ reducing\ poultry\ litter$$

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

(G8) $$P_M^B = \frac{WW^B}{N_M^B} \times \frac{DW^B}{WW^B} \times P_{DW}$$

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 needs be).

Appendix H: 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 enhanced nutrient management (ENM). 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.

To meet the NMP, farmers that currently apply more nitrogen 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 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 ENM, the operation must reduce nitrogen application by 15 percent from the amount needed for agricultural fields ($0.15N_A$). 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. We consider possible reduction in three sources of elemental nitrogen: 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 16 scenarios of nutrient removal, depending on the amount of nitrogen 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. To aid in comprehending these scenarios, we provide Appendix Table H1, which lists the variables used and provides descriptions of them.

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

(H1) $N_M = N_M^B + N_M^C$

Appendix Table H1: 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 nitrogen in recovered manure	Pounds
N_M^B	Recovered elemental nitrogen in recovered manure -- poultry	Pounds
N_M^C	Recovered elemental nitrogen in recovered manure – non-poultry livestock	Pounds
N_U	Elemental nitrogen used on crops and pastureland	Pounds
N_A	Elemental nitrogen applied to crops and pastureland	Pounds
N_F	Elemental nitrogen applied as fertilizer	Pounds
P_M^C	Price to remove a pound of elemental nitrogen in non-poultry livestock manure	Dollars
P_M^B	Price to remove a pound of elemental nitrogen in poultry litter	Dollars

Scenario 1: The operation produces no recoverable manure nitrogen

$N_M = 0$ and $N_F = N_A$

To meet the baseline NMP:

Amount of poultry litter exported: 0

Amount of other livestock manure exported: 0

To meet 15% reduction in nutrient application for ENMP:

Amount of fertilizer reduced: $0.15N_A$

Amount of poultry litter reduced: 0

Amount of other livestock manure reduced: 0

Scenario 2: The operation produces more recoverable manure nitrogen than is applied and only produces poultry litter.

$N_M \geq N_A$ and $N_F = 0$ and $N_M = N_M^B$ and $N_M^C = 0$

To meet the baseline NMP:

Amount of poultry litter exported: $N_M^B - N_A$

Amount of other livestock manure exported: 0

To meet 15% reduction in nutrient application for ENMP:

Amount of fertilizer reduced: 0
Amount of poultry litter reduced: $0.15N_A$
Amount of other livestock manure reduced: 0

Scenario 3: The operation produces more recoverable manure nitrogen than is applied and only produces manure from non-poultry livestock.

$N_M \geq N_A$ and $N_F = 0$ and $N_M = N_M^C$ and $N_M^B = 0$

To meet the baseline NMP:

Amount of poultry litter exported: 0
Amount of other livestock manure exported: $N_M^C - N_A$

To meet 15% reduction in nutrient application for ENMP:

Amount of fertilizer reduced: 0
Amount of poultry litter reduced: 0
Amount of other livestock manure reduced: $0.15N_A$

Scenario 4: The operation produces more recoverable manure nitrogen than is applied and produces both poultry litter and manure from non-poultry livestock. The shipping price per pound of nitrogen in poultry litter is greater than the shipping price per pound of nitrogen in non-poultry manure. The amount of recovered nitrogen in non-poultry manure is greater than the difference between the amount generated and the amount needed plus the 15% reduction in nitrogen applied.

$N_M \geq N_A$ $N_F = 0$ $N_M^C > 0$ $N_M^B > 0$ $P_M^B > P_M^C$

$N_M^C > N_M - N_A$ $N_M^C - (N_M - N_A) \geq .15N_A$

To meet the baseline NMP:

Amount of poultry litter exported: 0
Amount of other livestock manure exported: $N_M^C - N_A$

To meet 15% reduction in nutrient application for ENMP:

Amount of fertilizer reduced: 0
Amount of poultry litter reduced: 0
Amount of other livestock manure reduced: $0.15N_A$

Scenario 5: Operation produces more recoverable manure nitrogen than needed and produces both poultry litter and manure from non-poultry livestock. The shipping price per pound of nitrogen in poultry litter is greater than the shipping price per pound of nitrogen in non-poultry manure. The amount of recovered nitrogen in non-poultry manure is greater than the difference between the amount generated and the amount needed, but the remaining nitrogen in non-poultry manure is less than the 15% reduction in nitrogen applied.

$N_M \geq N_A$ $N_F = 0$ $N_M^C > 0$ $N_M^B > 0$ $P_M^B > P_M^C$

$N_M^C > N_M - N_A$ $N_M^C - (N_M - N_A) < .15N_A$

To meet the baseline NMP:

Amount of poultry litter exported:	0
Amount of other livestock manure exported:	$N_M^C - N_A$

To meet 15% reduction in nutrient application for ENMP:

Amount of fertilizer reduced:	0
Amount of poultry litter reduced:	$0.15N_A - [N_M^C - (N_M - N_A)]$
Amount of other livestock manure reduced:	$N_M^C - (N_M - N_A)$

Scenario 6: Operation produces more recoverable manure nitrogen than needed and produces both poultry litter and manure from non-poultry livestock. The shipping price per pound of nitrogen in poultry litter is greater than the shipping price per pound of nitrogen in non-poultry manure. The amount of recovered nitrogen in non-poultry manure is less than the difference between the amount generated and the amount needed.

$N_M \geq N_A$ $N_F = 0$ $N_M^C > 0$ $N_M^B > 0$ $P_M^B > P_M^C$

$N_M^C < N_M - N_A$

To meet the baseline NMP:

Amount of poultry litter exported:	$(N_M - N_A) - N_M^C$
Amount of other livestock manure exported:	N_M^C

To meet 15% reduction in nutrient application for ENMP:

Amount of fertilizer reduced:	0
Amount of poultry litter reduced:	$0.15N_A$
Amount of other livestock manure reduced:	0

Scenario 7: Operation produces more recoverable manure nitrogen than needed and produces both poultry litter and manure from non-poultry livestock. The shipping price per pound of nitrogen in poultry litter is less than the shipping price per pound of nitrogen in non-poultry manure. The amount of recovered nitrogen in poultry litter is greater than the difference between the amount generated and the amount needed plus the 15% reduction in nitrogen applied.

$N_M \geq N_A$ $N_F = 0$ $N_M^C > 0$ $N_M^B > 0$ $P_M^B < P_M^C$

$N_M^B > N_M - N_A$ $N_M^B - (N_M - N_A) \geq .15N_A$

To meet the baseline NMP:
Amount of poultry litter exported: $N_M^B - N_A$
Amount of other livestock manure exported: 0

To meet 15% reduction in nutrient application for ENMP:
Amount of fertilizer reduced: 0
Amount of poultry litter reduced: $0.15N_A$
Amount of other livestock manure reduced: 0

Scenario 8: Operation produces more recoverable manure nitrogen than needed and produces both poultry litter and manure from non-poultry livestock. The shipping price per pound of nitrogen in poultry litter is less than the shipping price per pound of nitrogen in non-poultry manure. The amount of recovered nitrogen in poultry litter is greater than the difference between the amount generated and the amount needed, but the remaining nitrogen in poultry litter is less than the 15% reduction in nitrogen applied.

$N_M \geq N_A$ $N_F = 0$ $N_M^C > 0$ $N_M^B > 0$ $P_M^B < P_M^C$

$N_M^B > N_M - N_A$ $N_M^B - (N_M - N_A) < .15N_A$

To meet the baseline NMP:
Amount of poultry litter exported: $N_M^C - N_A$
Amount of other livestock manure exported: 0

To meet 15% reduction in nutrient application for ENMP:
Amount of fertilizer reduced: 0
Amount of poultry litter reduced: $N_M^B - (N_M - N_A)$
Amount of other livestock manure reduced: $0.15N_A - [N_M^B - (N_M - N_A)]$

Scenario 9: Operation produces more recoverable manure nitrogen than needed and produces both poultry litter and manure from non-poultry livestock. The shipping price per pound of nitrogen in poultry litter is less than the shipping price per pound of nitrogen in non-poultry manure. The amount of recovered nitrogen in poultry litter is less than the difference between the amount generated and the amount needed.

$N_M \geq N_A$ $N_F = 0$ $N_M^C > 0$ $N_M^B > 0$ $P_M^B < P_M^C$

$N_M^B < N_M - N_A$

To meet the baseline NMP:

Amount of poultry litter exported: N_M^B

Amount of other livestock manure exported: $(N_M - N_A) - N_M^B$

To meet 15% reduction in nutrient application for ENMP:

Amount of fertilizer reduced: 0

Amount of poultry litter reduced: 0

Amount of other livestock manure reduced: $0.15N_A$

Scenario 10: Operation produces less recoverable manure nitrogen than needed and therefore uses fertilizer. Further, the amount of manure nitrogen used is less than 85% of the nitrogen applied.

$N_M < N_A$ $\quad N_F = N_A - N_M$ $\quad N_M < 0.85N_A$

To meet the baseline NMP:

Amount of poultry litter exported: 0

Amount of other livestock manure exported: 0

To meet 15% reduction in nutrient application for ENMP:

Amount of fertilizer reduced: $0.15N_A$

Amount of poultry litter reduced: 0

Amount of other livestock manure reduced: 0

Scenario 11: Operation produces less recoverable manure nitrogen than needed and therefore uses fertilizer. The amount of manure nitrogen used is greater than 85% of the nitrogen applied. Only poultry litter is applied.

$N_M < N_A$ $\quad N_F = N_A - N_M$ $\quad N_M > 0.85N_A$ $\quad N_M^C = 0$

$N_M^B > 0$

To meet the baseline NMP:

Amount of poultry litter exported: 0

Amount of other livestock manure exported: 0

To meet 15% reduction in nutrient application for ENMP:

Amount of fertilizer reduced: N_F

Amount of poultry litter reduced: $0.15N_A - N_F$

Amount of other livestock manure reduced: 0

Scenario 12: Operation produces less recoverable manure nitrogen than needed and therefore uses fertilizer. The amount of manure nitrogen used is greater than 85% of the nitrogen applied. Only non-poultry manure is applied.

$N_M < N_A$ $N_F = N_A - N_M$ $N_M > 0.85N_A$ $N_M^C > 0$ $N_M^B = 0$

<u>To meet the baseline NMP:</u>

Amount of poultry litter exported:	0
Amount of other livestock manure exported:	0

<u>To meet 15% reduction in nutrient application for ENMP:</u>

Amount of fertilizer reduced:	N_F
Amount of poultry litter reduced:	0
Amount of other livestock manure reduced:	$0.15N_A - N_F$

Scenario 13: Operation produces less recoverable manure nitrogen than needed and therefore uses fertilizer. The amount of manure nitrogen used is greater than 85% of the nitrogen applied. Both poultry litter and non-poultry manure are applied. The shipping price per pound of nitrogen in poultry litter is less than the shipping price per pound of nitrogen in non-poultry manure. The amount of nitrogen in poultry litter produced exceeds 15% of the nitrogen applied minus the amount of nitrogen in fertilizer used.

$N_M < N_A$ $N_F = N_A - N_M$ $N_M > 0.85N_A$ $N_M^C > 0$ $N_M^B > 0$

$P_M^B < P_M^C$ $N_M^B > 0.15N_A - N_F$

<u>To meet the baseline NMP:</u>

Amount of poultry litter exported:	0
Amount of other livestock manure exported:	0

<u>To meet 15% reduction in nutrient application for ENMP:</u>

Amount of fertilizer reduced:	N_F
Amount of poultry litter reduced:	$0.15N_A - N_F$
Amount of other livestock manure reduced:	0

Scenario 14: Operation produces less recoverable manure nitrogen than needed and therefore uses fertilizer. The amount of manure nitrogen used is greater than 85% of the nitrogen applied. Both poultry litter and non-poultry manure are applied. The shipping price per pound of nitrogen in poultry litter is greater than the shipping price per pound of nitrogen in non-poultry manure. The amount of nitrogen in non-poultry manure produced exceeds 15% of the nitrogen applied minus the amount of nitrogen in fertilizer used.

$N_M < N_A$ $N_F = N_A - N_M$ $N_M > 0.85N_A$ $N_M^C > 0$ $N_M^B > 0$

$P_M^B > P_M^C$ $N_M^C > 0.15N_A - N_F$

To meet the baseline NMP:

Amount of poultry litter exported:	0
Amount of other livestock manure exported:	0

To meet 15% reduction in nutrient application for ENMP:

Amount of fertilizer reduced:	N_F
Amount of poultry litter reduced:	0
Amount of other livestock manure reduced:	$0.15N_A - N_F$

Scenario 15: Operation produces less recoverable manure nitrogen than needed and therefore uses fertilizer. The amount of manure nitrogen used is greater than 85% of the nitrogen applied. Both poultry litter and non-poultry manure are applied. The shipping price per pound of nitrogen in poultry litter is greater than the shipping price per pound of nitrogen in non-poultry manure. The amount of nitrogen in non-poultry manure produced is less than 15% of the nitrogen applied minus the amount of nitrogen in fertilizer used.

$N_M < N_A$ $N_F = N_A - N_M$ $N_M > 0.85N_A$ $N_M^C > 0$ $N_M^B > 0$

$P_M^B > P_M^C$ $N_M^C < 0.15N_A - N_F$

To meet the baseline NMP:

Amount of poultry litter exported:	0
Amount of other livestock manure exported:	0

To meet 15% reduction in nutrient application for ENMP:

Amount of fertilizer reduced:	N_F
Amount of poultry litter reduced:	$0.15N_A - N_F - N_M^C$
Amount of other livestock manure reduced:	N_M^C

Scenario 16: Operation produces less recoverable manure nitrogen than needed and therefore uses fertilizer. The amount of manure nitrogen used is greater than 85% of the nitrogen applied. Both poultry litter and non-poultry manure are applied. The shipping price per pound of nitrogen in poultry litter is less than the shipping price per pound of nitrogen in non-poultry manure. The amount of nitrogen in poultry litter produced is less than 15% of the nitrogen applied minus the amount of nitrogen in fertilizer used.

$N_M < N_A$ $N_F = N_A - N_M$ $N_M > 0.85N_A$ $N_M^C > 0$ $N_M^B > 0$

$P_M^B < P_M^C$ $N_M^B < 0.15N_A - N_F$

To meet the baseline NMP:

Amount of poultry litter exported:	0
Amount of other livestock manure exported:	0

To meet 15% reduction in nutrient application for ENMP:

Amount of fertilizer reduced:	N_F
Amount of poultry litter reduced:	N_M^B
Amount of other livestock manure reduced:	$0.15N_A - N_F - N_M^B$

Appendix I: Additional Results

Appendix Table I1: Percentage of Farms with Land Uses and Average Acreage in Specific Use, Chesapeake Bay Counties, 2007

	% with Crop Acreage	Average Cropland (acres): Farms with Non-Zero Values	Average Cropland (acres): All Farms	% with Pasture Acreage	Average Pastureland (acres): Farms with Non-Zero Values	Average Pastureland (acres): All Farms
All	**76%**	**106**	**81**	**69%**	**51**	**35**
No livestock -- Less than 100 acres of cropland	84%	29	25	35%	46	16
No livestock -- 100 or more acres of cropland	100%	420	420	29%	73	21
Some livestock but not likely to be confined	66%	66	43	91%	49	44
Potential Small CAFOs	91%	182	165	77%	54	42
Potential Medium CAFOs	71%	383	272	56%	107	60
Potential Large CAFOs	72%	656	472	53%	129	68

	% with Fertilized Acreage	Average Fertilized Acres: Farms with Non-Zero Values	Average Fertilized Acres: All Farms	% with Manure Applied Acreage	Average Manure-Applied Acres: Farms with Non-Zero Values	Average Manure-Applied Acres: All Farms
All	**46%**	**117**	**54**	**28%**	**72**	**20**
No livestock -- Less than 100 acres of cropland	38%	22	8	9%	21	2
No livestock -- 100 or more acres of cropland	77%	418	321	22%	150	34
Some livestock but not likely to be confined	41%	66	27	29%	31	9
Potential Small CAFOs	75%	152	114	67%	108	72
Potential Medium CAFOs	50%	419	211	49%	285	139
Potential Large CAFOs	51%	696	356	51%	475	240

Appendix Table I2: Crops and Livestock in Chesapeake Bay Counties, Averages by Farm and Totals for All Counties, 2007

	Farms with non-zero value	Average Yield Per Farm -- Farms with non-zero values	Total - All Farms
Crop and Pasture			
Corn for grain (bushels)	20,475	10,437	213,696,135
Corn for silage (tons)	13,688	844	11,549,847
Soybeans (bushels)	10,424	3,886	40,502,513
Sorghum for grain (bushels)	225	2,048	460,829
Sorghum for silage (tons)	470	135	53,707
Cotton (bales)	88	610	63,644
Barley (bushels)	3,406	2,773	9,446,321
Wheat (bushels)	7,211	4,868	35,104,111
Oats (bushels)	4,463	1,084	4,837,066
Rye for grain (bushels)	1,005	564	566,559
Peanuts for nuts (pounds)	77	353,818	27,243,950
Tobacco (pounds)	1,294	17,759	22,980,415
Alfalfa and other hay (tons)	54,437	106	5,759,724
Grass silage (tons)	4,446	240	1,067,136
Cropland used as pasture (acres)	21,695	36	786,785
Permanent pastureland (acres)	60,399	41	2,505,014
Livestock Animal Units			
Fattened cattle and veal calves	5,737	22	124,120
Dairy cows	11,254	105	1,183,596
Swine	4,894	43	210,406
Poultry	15,835	491	7,774,661
Confined pastured livestock types	6,444	15	96,479
Pastured livestock	58,531	20	1,176,009
Specialty livestock	5,828	3	15,073

Appendix Table I3: Percentage of Operations with Different Types of Livestock, by Type of Operation, Chesapeake Bay Counties, 2007

	Animal Type						
	Fattened cattle and veal calves	**Dairy cows**	**Swine**	**Poultry**	**Confined pastured livestock types**	**Pastured livestock**	**Specialty livestock**
Some livestock but not likely to be confined	7%	2%	6%	18%	7%	86%	9%
Potential Small CAFOs	13%	74%	7%	25%	19%	73%	4%
Potential Medium CAFOs	8%	24%	12%	71%	9%	40%	1%
Potential Large CAFOs	9%	18%	23%	71%	11%	35%	2%

Appendix Table I4: Percentage of Operations with Different Types of Crops and Pastureland, by Type of Operation, Chesapeake Bay Counties, 2007

	Commodity							
	Corn for grain (bushels)	Corn for silage (tons)	Soybeans (bushels)	Sorghum for grain (bushels)	Sorghum for silage (tons)	Cotton (bales)	Barley (bushels)	Wheat (bushels)
No livestock -- Less than 100 acres of cropland	9.5%	1.9%	5.6%	0.1%	0.0%	0.0%	0.6%	2.9%
No livestock -- 100 or more acres of cropland	57.3%	11.4%	48.7%	1.2%	0.5%	0.9%	8.0%	34.6%
Some livestock but not likely to be confined	11.6%	5.9%	4.1%	0.1%	0.2%	0.0%	1.7%	3.6%
Potential Small CAFOs	50.1%	64.5%	20.5%	0.3%	2.2%	0.0%	11.5%	13.3%
Potential Medium CAFOs	42.6%	31.5%	28.4%	0.9%	0.8%	0.1%	12.0%	17.4%
Potential Large CAFOs	47.2%	31.8%	30.6%	1.7%	0.3%	0.0%	9.0%	21.4%
	Oats (bushels)	Rye for grain (bushels)	Peanuts for nuts (pounds)	Tobacco (pounds)	Alfalfa and other hay (tons)	Grass silage (tons)	Cropland used as pasture (acres)	Permanent pastureland (acres)
No livestock -- Less than 100 acres of cropland	1.5%	0.3%	0.0%	0.3%	33.1%	1.2%	12.1%	23.9%
No livestock -- 100 or more acres of cropland	7.1%	2.5%	0.7%	0.7%	42.3%	3.7%	8.0%	22.4%
Some livestock but not likely to be confined	3.8%	0.5%	0.0%	0.5%	55.1%	3.0%	24.4%	75.2%
Potential Small CAFOs	10.7%	2.8%	0.0%	6.6%	76.7%	15.1%	26.0%	66.2%
Potential Medium CAFOs	2.9%	2.7%	0.1%	0.8%	43.2%	8.4%	20.3%	43.2%
Potential Large CAFOs	2.1%	4.5%	0.0%	1.2%	43.9%	8.3%	15.9%	42.1%

Appendix Table I5: Average Yields of Crops and Average Amount of Pastureland, by Type of Operation, Chesapeake Bay Counties, 2007

	Commodity							
	Corn for grain (bushels)	Corn for silage (tons)	Soybeans (bushels)	Sorghum for grain (bushels)	Sorghum for silage (tons)	Cotton (bales)	Barley (bushels)	Wheat (bushels)
No livestock -- Less than 100 acres of cropland	198	5	40	0	0	0	5	25
No livestock -- 100 or more acres of cropland	15,052	118	3,495	34	1	7	517	3,272
Some livestock but not likely to be confined	555	20	109	1	0	0	26	101
Potential Small CAFOs	4,085	477	552	5	3	0	236	388
Potential Medium CAFOs	9,327	889	1,499	26	2	0	504	1,131
Potential Large CAFOs	18,399	1,895	2,594	96	3	0	708	2,460
	Oats (bushels)	Rye for grain (bushels)	Peanuts for nuts (pounds)	Tobacco (pounds)	Alfalfa and other hay (tons)	Grass silage (tons)	Cropland used as pasture (acres)	Permanent pastureland (acres)
No livestock -- Less than 100 acres of cropland	6	1	2	42	15	1	6	8
No livestock -- 100 or more acres of cropland	190	18	2,557	388	107	12	5	13
Some livestock but not likely to be confined	25	2	147	96	47	4	8	30
Potential Small CAFOs	151	12	284	1,051	132	43	9	28
Potential Medium CAFOs	81	40	127	253	121	64	11	41
Potential Large CAFOs	50	77	0	294	153	77	13	46

Notes: Table shows averages for all operations in Chesapeake Bay water counties, not just those with non-zero values for the specific commodity.

Appendix Table I6: Average Dollar Amount Lost in from Yield Reduction Due to Nutrient Reduction: Different Types of Crops, by Type of Operation, Chesapeake Bay Counties, 2007

	Commodity						
	Corn for grain	Corn for silage	Soybeans	Sorghum for grain	Sorghum for silage	Cotton	Barley
No livestock -- Less than 100 acres of cropland	209	417	340	0	6	18	5
No livestock -- 100 or more acres of cropland	11,023	6,362	20,703	24	47	5,720	369
Some livestock but not likely to be confined	366	966	582	1	10	115	17
Potential Small CAFOs	2,702	23,298	2,951	3	132	75	152
Potential Medium CAFOs	7,318	51,500	9,514	20	137	336	386
Potential Large CAFOs	15,131	115,084	17,251	78	189	0	567
	Wheat	Oats	Rye for grain	Peanuts for nuts	Tobacco	Alfalfa and other hay	Grass silage
No livestock -- Less than 100 acres of cropland	38	3	2	0	1	17,271	79
No livestock -- 100 or more acres of cropland	3,462	63	24	334	4	95,431	1,000
Some livestock but not likely to be confined	96	7	3	17	1	34,136	286
Potential Small CAFOs	371	46	14	34	10	122,526	3,196
Potential Medium CAFOs	1,284	29	56	18	3	123,189	5,628
Potential Large CAFOs	2,927	19	114	0	3	147,056	7,147

Notes: Losses shown for all potential participants in nutrient trading. Amounts lost are due to a 10% reduction in yields assumed due to a 15% reduction in nitrogen application.

Appendix Table I7: Sensitivity Analyses: Effects of Parameter and Assumption Changes from "Base" Scenario on Percentage of Possible Participants Finding it Cost-Beneficial to Participate and the Average Net Value of Credits for All Possible Participants

		Change in Parameter or Assumption from "Base" Scenario					
Type of Farm	"Base" Scenario	5% loss in yield	15% loss in yield	2007 crop and fertilizer prices	High estimate manure shipping costs	Large CAFOs do not have prior regulation	Application removal rate of 1.4
Percentage of possible participants finding it cost-beneficial to participate							
All	35.7%	39.9%	32.7%	36.5%	35.7%	35.6%	36.7%
No livestock -- Less than 100 acres of cropland	38.4%	41.2%	33.4%	38.8%	38.4%	38.4%	39.5%
No livestock -- 100 or more acres of cropland	47.1%	55.2%	33.0%	48.9%	47.1%	47.1%	49.5%
Some livestock but not likely to be confined	40.6%	43.9%	39.2%	41.1%	40.6%	40.6%	41.4%
Potential Small CAFOs	5.3%	13.3%	3.7%	7.4%	5.3%	5.3%	6.5%
Potential Medium CAFOs	33.4%	41.7%	25.1%	35.2%	33.3%	33.4%	34.9%
Potential Large CAFOs	36.4%	45.9%	30.0%	39.5%	36.4%	26.6%	38.9%
Average Net Value of Credits -- All Possible Participants							
All	-$44,361	-$14,209	-$74,512	-$33,153	-$44,708	-$44,329	-$41,210
No livestock -- Less than 100 acres of cropland	-$14,101	-$4,906	-$23,296	-$11,527	-$14,101	-$14,101	-$13,326
No livestock -- 100 or more acres of cropland	-$53,037	$19,246	-$125,320	-$28,819	-$53,037	-$53,037	-$36,796
Some livestock but not likely to be confined	-$28,352	-$10,050	-$46,653	-$23,184	-$28,352	-$28,352	-$26,879
Potential Small CAFOs	-$146,949	-$61,630	-$232,269	-$106,935	-$149,769	-$146,949	-$138,280
Potential Medium CAFOs	-$141,927	-$36,378	-$247,475	-$92,786	-$142,379	-$141,927	-$129,273
Potential Large CAFOs	-$181,503	-$28,721	-$334,286	-$109,733	-$181,567	-$212,588	-$159,612

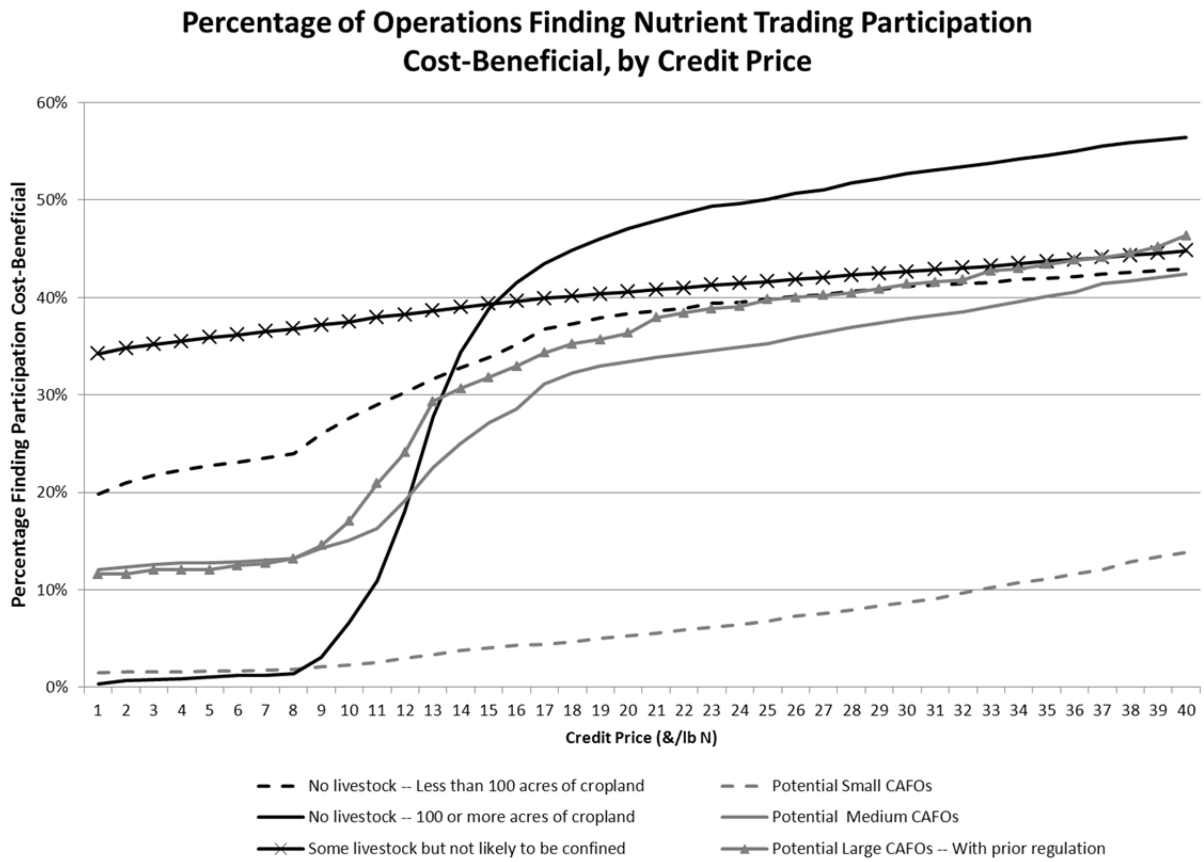
Baseline scenario: 2011 prices for crops and fertilizer, $20 credit price, 10% loss in yield from enhanced nutrient management, "base" scenario manure shipping costs, large CAFOs assumed to already satisfy NMPs, and application-removal ratio of 1.2.

Appendix Table I8: Sensitivity Analyses: Effects of Parameter and Assumption Changes from "Base" Scenario on the Average Net Value of Credits for Operations Finding Participation Cost-Beneficial

		Change in Parameter or Assumption from "Base" Scenario					
Type of Farm	"Base" Scenario	5% loss in yield	15% loss in yield	2007 crop and fertilizer prices	High estimate manure shipping costs	Large CAFOs do not have prior regulation	Application removal rate of 1.4
Average Net Value of Credits -- Operations Finding Participation Cost-Beneficial							
All	$10,595	$14,171	$7,779	$10,587	$10,595	$10,587	$13,568
No livestock -- Less than 100 acres of cropland	$3,642	$4,100	$3,620	$3,642	$3,642	$3,642	$4,374
No livestock -- 100 or more acres of cropland	$74,994	$96,815	$62,414	$74,994	$74,994	$74,994	$95,783
Some livestock but not likely to be confined	$4,085	$4,982	$3,575	$4,085	$4,085	$4,085	$5,013
Potential Small CAFOs	$48,206	$33,224	$52,934	$48,206	$48,202	$48,206	$51,082
Potential Medium CAFOs	$21,076	$34,796	$9,960	$21,076	$21,113	$21,076	$29,835
Potential Large CAFOs	$39,259	$65,532	$14,815	$47,602	$39,212	$47,602	$54,461

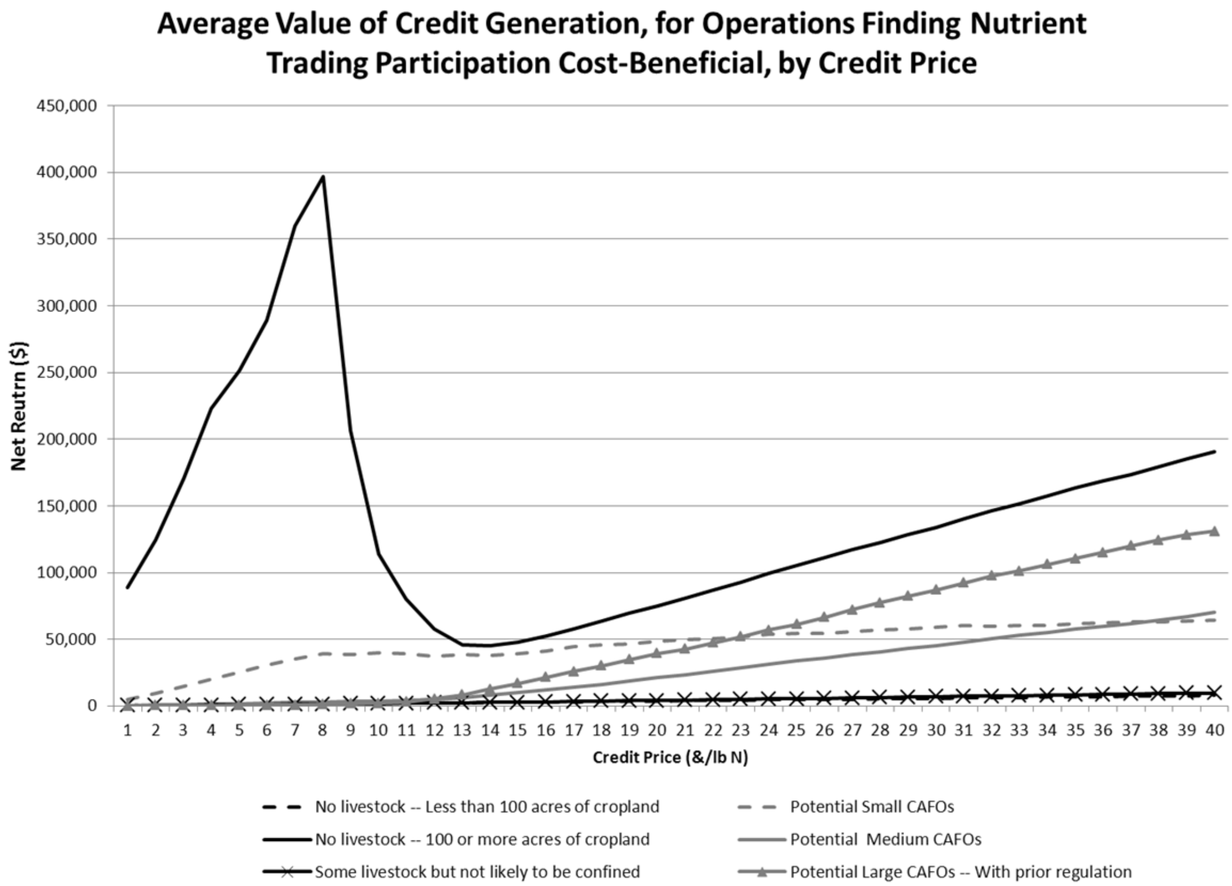
Baseline scenario: 2011 prices for crops and fertilizer, $20 credit price, 10% loss in yield from enhanced nutrient management, "base" scenario manure shipping costs, large CAFOs assumed to already satisfy NMPs, and application-removal ratio of 1.2.

Appendix Fig. I1



Note: Shows percentage of possible participants that would realize a net benefit greater than zero from participating in nutrient trading via enhanced nutrient trading. Other than credit price, all "base" scenario parameters and assumptions are used. See main text for more detail.

Appendix Fig. I2



Note: Shows the average net value of credits for operations realizing a net benefit greater than zero from participating in nutrient trading via enhanced nutrient trading. Other than credit price, all "base" scenario parameters and assumptions are used. See main text for more detail.

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