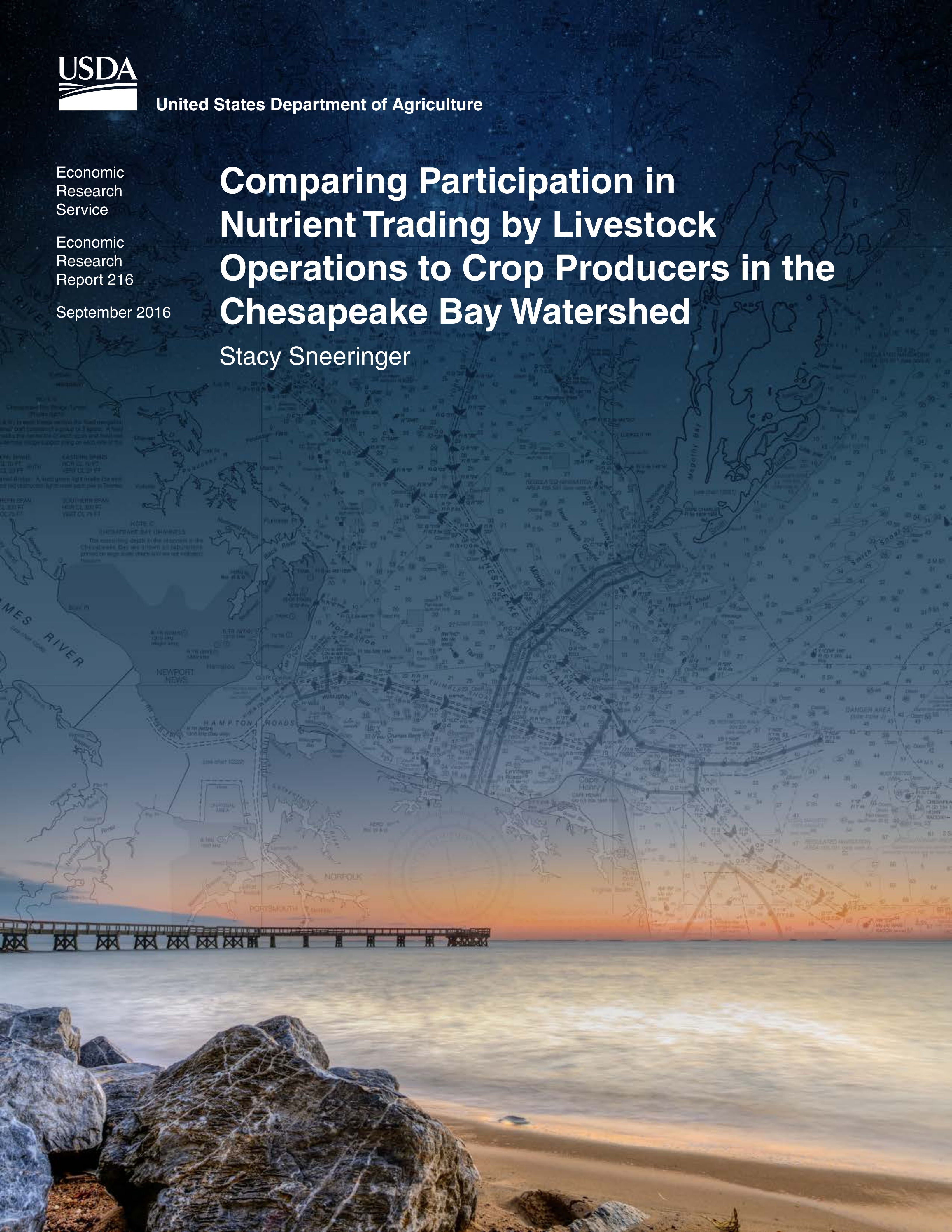


United States Department of Agriculture

Economic
Research
Service

Economic
Research
Report 216

September 2016

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

Stacy Sneeringer

United States Department of Agriculture

Economic Research Service
www.ers.usda.gov

Access this report online:

www.ers.usda.gov/publications/err-economic-research-report/err-216

Download the charts contained in this report:

- Go to the report's index page www.ers.usda.gov/publications/err-economic-research-report/err216
- Click on the bulleted item "Download err216.zip"
- Open the chart you want, then save it to your computer

Recommended citation format for this publication:

Stacy Sneeringer. *Comparing Participation in Nutrient Trading by Livestock Operations to Crop Producers in the Chesapeake Bay Watershed,* ERR-216, U.S. Department of Agriculture, Economic Research Service, September 2016.

Cover is a derivative of images from iStock.

Use of commercial and trade names does not imply approval or constitute endorsement by USDA.

To ensure the quality of its research reports and satisfy government-wide standards, ERS requires that all research reports with substantively new material be reviewed by qualified technical research peers. This technical peer review process, coordinated by ERS' Peer Review Coordinating Council, allows experts who possess the technical background, perspective, and expertise to provide an objective and meaningful assessment of the output's substantive content and clarity of communication during the publication's review. For more information on the Agency's peer review process, go to: http://www.ers.usda.gov/about-ers/peer-reviews.aspx

---

In accordance with Federal civil rights law and U.S. Department of Agriculture (USDA) civil rights regulations and policies, the USDA, its Agencies, offices, and employees, and institutions participating in or administering USDA programs are prohibited from discriminating based on race, color, national origin, religion, sex, gender identity (including gender expression), sexual orientation, disability, age, marital status, family/parental status, income derived from a public assistance program, political beliefs, or reprisal or retaliation for prior civil rights activity, in any program or activity conducted or funded by USDA (not all bases apply to all programs). Remedies and complaint filing deadlines vary by program or incident.

Persons with disabilities who require alternative means of communication for program information (e.g., Braille, large print, audiotape, American Sign Language, etc.) should contact the responsible Agency or USDA's TARGET Center at (202) 720-2600 (voice and TTY) or contact USDA through the Federal Relay Service at (800) 877-8339. Additionally, program information may be made available in languages other than English.

To file a program discrimination complaint, complete the USDA Program Discrimination Complaint Form, AD-3027, found online at How to File a Program Discrimination Complaint and at any USDA office or write a letter addressed to USDA and provide in the letter all of the information requested in the form. To request a copy of the complaint form, call (866) 632-9992. Submit your completed form or letter to USDA by: (1) mail: U.S. Department of Agriculture, Office of the Assistant Secretary for Civil Rights, 1400 Independence Avenue, SW, Washington, D.C. 20250-9410; (2) fax: (202) 690-7442; or (3) email: program.intake@usda.gov.

USDA is an equal opportunity provider, employer, and lender.

United States Department of Agriculture

Economic Research Service

Economic Research Report 216

September 2016

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

Stacy Sneeringer

Abstract

Despite decades of nutrient-runoff reduction efforts via regulation, financial and technical assistance, and education, manure remains a significant contributor to Chesapeake Bay nutrient loadings. In the Bay watershed, animal feeding operations (AFOs; livestock operations that confine animals) are responsible for the majority of acreage onto which manure is applied, and over a quarter of these operations produce more manure nutrients than they can use on the farm. An alternative method of reducing discharges from livestock operations may be to involve them in nutrient trading, in which producers sell representations of their pollution reductions as credits. Past analysis of farmer participation in nutrient trading has focused almost exclusively on crop producers. In contrast to crop-only producers, livestock producers face regulations that require them to meet nutrient application standards on their farms, and they have added costs of manure shipping to meet those standards. Therefore, they may be less likely to participate in nutrient trading than crop-only producers. An analysis of producer-participation decisions reveals that those producing more manure nutrients than can be applied on their farms are especially unlikely to participate in nutrient trading based on reductions in nutrient applications to cropland. Since these operations already have relatively little cropland, they can generate relatively few credits from pollution reductions.

Keywords: Livestock, nutrients, nutrient trading, water quality trading, Chesapeake Bay, total maximum daily load, TMDL

Acknowledgments

The authors wish to thank Ann Wolverton, U.S. Environmental Protection Agency; Kathryn Zook, U.S. Department of Agriculture, Office of the Chief Economist; Marc Ribaudo, U.S. Department of Agriculture, Economic Research Service; and an anonymous reviewer for their peer reviews. Policy reviews were also provided by Noel Gollehon, Jeff Porter, Mark Peters, and members of the Resource Economics and Analysis Division, U.S. Department of Agriculture, Natural Resources Conservation Service; Bruce Boess and Tom Kruchten, U.S. Department of Agriculture, National Agricultural Statistics Service; and Mindy Selman of the U.S. Department of Agriculture, Office of the Chief Economist. We also thank Priscilla Smith, Dale Simms, and Ethiene Salgado-Rodriguez of ERS for editorial and design services.

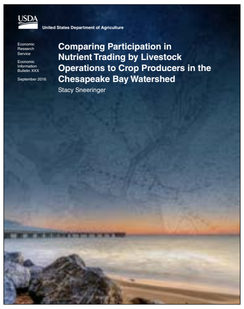
Contents

Appendixes A-J can be found at:

http://www.ers.usda.gov/publications/err-economic-research-report/err216.aspx

United States Department of Agriculture

A report summary from the Economic Research Service September 2016



United States Department of Agriculture

Economic
Research
Service

Economic
Information
Bulletin XXX

September 2016

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

Stacy Sneeringer

Find the full report at *www.ers.usda.gov/publications/err-economic-research-report/err-216*

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

Stacy Sneeringer

What Is the Issue?

Despite decades of recuperation efforts, the Chesapeake Bay's water quality has not met desired goals. This has prompted the U.S. Environmental Protection Agency (EPA) to adopt a limit on the amount of pollutants that the watershed can receive and still meet water-quality goals, called a total maximum daily load (TMDL). Specific pollutants of concern in the Chesapeake Bay include nitrogen and phosphorus, nutrients that can lead to adverse effects on public health, recreation, and ecosystems if present in excess amounts. The EPA estimates that the application of commercial fertilizer and manure to agricultural land contributes at least 39 percent of nitrogen and 57 percent of phosphorus loadings to the Chesapeake Bay. Of those agricultural loadings, approximately half are due to applications of commercial fertilizer, while half are due to manure.

Two highlights of States' TMDL implementation plans are greater oversight of discharges from animal feeding operations (AFOs) and nutrient trading. AFOs are livestock operations that raise animals in confinement. Certain AFOs, called confined animal feeding operations (CAFOs) are regulated under the Clean Water Act (CWA). However, CWA regulations do not fully satisfy water-quality goals, in part because many AFOs fall outside of regulatory purview. To address potential runoff from these operations, Federal, State, and local governments offer outreach, education, and financial assistance to encourage adoption of practices that are less polluting. But recent studies have shown that agricultural operations do not implement these practices to the extent necessary to satisfy water quality goals.

Nutrient trading is a system in which polluters with higher costs of pollution reductions (e.g., wastewater treatment facilities) pay those with lower costs (like agricultural producers) to limit discharges. Before they can generate pollution reduction credits for sale, agricultural producers must first meet baseline requirements, including shipping any excess manure nutrients off-farm. The literature on nutrient trading in the Chesapeake Bay almost exclusively considers crop agriculture, overlooking several factors that may affect livestock producers' participation in nutrient trading.

This report builds on the June 2014 USDA, Economic Research Service report, *An Economic Assessment of Policy Options To Reduce Agricultural Pollutants in the Chesapeake Bay*, by providing a more detailed examination of nutrient-management complexities and participation in nutrient-trading, according to farm type. It addresses the extent to which AFOs are implicated in Chesapeake Bay nutrient pollution and compares nutrient-trading participation in AFOs versus crop-only farms and by AFOs of different sizes.

What Did the Study Find?

AFOs (of which CAFOs are a subset) are responsible for the majority of manure acreage in the Chesapeake Bay, and just over a quarter of these operations produce more recoverable manure nutrients than can be used on a given farm.

- In 2012, an estimated 46 percent of recoverable manure nitrogen and 60 percent of the recoverable manure phosphorus in the Bay was produced on farms without enough crop and pastureland assimilative capacity to accommodate the manure nutrients.
- Though they constitute only 15 percent of agricultural operations and cover only 30 percent of crop and pastureland in the Chesapeake Bay watershed, AFOs controlled 63 percent of the acreage to which manure is applied (manure acreage) in 2012.
- AFOs are more likely than other types of farms to apply manure, but not all of them do. Only 60 percent of AFOs report applying manure to crop or pastureland, although 92 percent of them have such land.
- Twenty-six percent of Chesapeake Bay AFOs produce (via manure) more nitrogen than can be assimilated on the farms where it is produced. Forty-six percent of AFOs produce more phosphorus than can be used on the farms.

The CWA CAFO regulations and other differences between livestock and crop-only farms may create differences in the likelihood and benefits of participating in nutrient trading.

- To meet baseline requirements for nutrient trading, producers must satisfy all regulations. Actual or perceived regulation may deter livestock operations from approaching the trading authority.
- In many nutrient-trading schemes, an aspect of meeting the baseline is a nutrient management plan (NMP) requiring that nutrient applications do not exceed onfarm needs. Operations producing more manure nutrients than can be agronomically assimilated may incur costs for shipping nutrients off-farm in order to meet an NMP. Crop-only producers utilizing commercial fertilizer do not generate nutrients onsite, so they will not face these additional costs.
- Agricultural producers may generate nutrient reduction credits to sell when they lower nutrient discharges below the level allowed in an NMP. This reduction may require operations that generate manure to ship nutrients off-farm at an additional cost. Operations relying solely on commercial fertilizer can actually reduce an expense by lowering nutrient applications. An added cost for manure producers compares with a saved expense for crop-only producers.

In this report, we simulate trading whereby producers generate credits by reducing their onfarm applications of manure and fertilizer below the agronomic rates required to participate. Simulation results using a $20 per credit price show that AFOs without excess manure nutrients are as likely to participate as large-scale, crop-only producers. AFOs with excess manure nutrients are much less likely to be able to participate and, even if able, to find it cost-beneficial.

- Thirty-five percent of small AFOs with onfarm excess manure nutrients have no nutrient uptake capacity on cropland. In the modeled trading program, farmers generate credits by reducing applications to cropland. Because they cannot reduce applications to cropland, these producers are not potential trading participants. Around half of medium and large AFOs with excess manure nutrients also have no cropland (48 and 51 percent, respectively).

- Among AFOs with excess nutrients that are potential participants, only 35 percent of small AFOs would find it cost-beneficial to participate. In contrast, more than half of medium AFOs and 59 percent of large AFOs with excess nutrients would find participation cost-beneficial.
- AFOs with onfarm excess nutrients have relatively little cropland (when they have any at all). These farms, therefore, cannot generate as many credits from reduction of nutrient application to cropland; this means they cannot generate as much revenue from participating in nutrient trading as operations with more cropland.

How Was the Study Conducted?

This report describes livestock agriculture in the Chesapeake Bay using 2012 Census of Agriculture data. (The 2012 Census of Agriculture is the most recent one, conducted by the U.S. Department of Agriculture's National Agricultural Statistics Service in 2012, with the first data results released in mid-2014. The census is conducted every 5 years.) Next, measures of nutrient uptake and generation for every farm in the Bay watershed are estimated, using USDA Natural Resources Conservation Service (NRCS) methods, which account for animal type, region, crop yield, and production facility size. The effects of Clean Water Act regulations on livestock operations' participation in nutrient trading is discussed, and a numerical simulation model of agricultural operations' participation in nutrient trading via reduction of nutrients to cropland is constructed, accounting for yield reductions, manure-shipping costs, and multiple other factors. Finally, participation is predicted across types of producers, and sensitivity analyses are conducted by varying model parameter assumptions.

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

Introduction

The Chesapeake Bay watershed includes portions of six States and the District of Columbia, covering 64,000 square miles and more than 17 million people. The Bay is fed by five major rivers—the Susquehanna, Potomac, Rappahannock, York, and James—as well as their tributaries. Agriculture accounts for over a quarter of land in the Bay, with production of crops and livestock totaling approximately $15 billion in 2012.[1] (The 2012 Census of Agriculture is the most recent one, conducted by the U.S. Department of Agriculture's National Agricultural Statistics Service in 2012, with the first data results released in mid-2014. The census is conducted every 5 years.) The Bay also suffers significant water-quality concerns in the form of nutrient pollution, which can yield algal blooms, fish kills, impaired drinking-water supplies, and adverse public-health outcomes (Copeland, 2006). The Federal Clean Water Act (CWA), adopted in 1972, helped reduce pollution from specific point sources, such as wastewater treatment facilities, by requiring them to limit their discharges to permitted levels (written into National Pollution Discharge Elimination System (NPDES) permits). However, the original CWA did not address nonpoint-source pollution arising from agricultural fields and stormwater runoff (see box, "Point and Nonpoint-Source Pollution"). In the Chesapeake Bay, approximately half of the nutrient pollution is estimated to arise from nonpoint-source loadings from agriculture, with land application of fertilizer and manure[2] each contributing approximately half of the agricultural loadings (USEPA, 2009a). Manure can be applied either directly by pasture-based animals or after being collected in storage facilities. This agricultural pollution is largely unregulated except for some discharges from certain large-scale livestock operations.

Despite decades of restoration attempts, the Bay still fails to meet water-quality goals. In 2011-2013, only 29 percent of Bay waters met Clean Water Act standards for water quality (Chesapeake Bay Program, 2013). Differences in jurisdictional boundaries and a decentralized policy landscape are part of the difficulty in Bay-area cleanup. Because of continued problems, in 2010 the EPA adopted a total maximum daily load (TMDL) for the area, which sets a discharge limit for the watershed. States within the watershed must submit plans on how to reduce discharge levels to meet water-quality standards. These plans include load restrictions from unregulated nonpoint sources, like crop and most livestock producers, and regulated point sources, like wastewater treatment facilities. To achieve these reduced loadings, regulated point sources have more stringent loadings written into their individual permits, while unregulated nonpoint sources are asked to voluntarily reduce their discharges.

Given the importance of manure in agricultural loadings, State plans to meet the TMDL have included a focus on certain kinds of livestock operations. Animal feeding operations (AFOs) are

---

[1] The estimate of $15 billion comes from the author's calculations using 2012 Census of Agriculture data of the total value of production at farms in Chesapeake Bay watershed counties.

[2] This includes manure "deliberately" applied (as with confined animal feeding operations that collect manure for later land application) as well as manure "passively" applied (as with pastured animals that deposit manure directly to the land).

Point and Nonpoint-Source Pollution

Under regulatory protocols, pollutant discharges are characterized as “point source” and “nonpoint source.” A point source is a single identifiable outlet from which pollutants are discharged, such as a pipe, ditch, factory, or wastewater treatment facility. A nonpoint source of nutrient pollution is one with less discernible boundaries, like runoff from fields and impermeable surfaces. Most agricultural operations are potential nonpoint-source polluters, although confined animal feeding operations (CAFOs) are considered to have both point and nonpoint-source discharges. Point sources must obtain National Pollution Discharge Elimination System (NPDES) permits or other State equivalents. Nonpoint-source discharges are frequently unregulated. Reducing discharges from point sources like water-treatment facilities generally requires expensive technological upgrades. Discharge reductions from nonpoint sources are thought to be less expensive, generally requiring different land management techniques (Chesapeake Bay Commission, 2012).

Agricultural nonpoint sources and loadings are much more numerous than agricultural point-source loadings. The primary forms of nonpoint-source loadings from agriculture are land application of fertilizer and manure at rates above which crops and pasture can assimilate. Precipitation can then wash excess nutrients to surface and ground water; this process is typically referred to as “runoff” (Gollehon and Caswell 2000). Agricultural point-source pollution can arise from the manure storage areas of CAFOs, which can leak or overflow. In tallies of the sources of Chesapeake Bay nutrient loadings, the extent of point-source discharges from CAFOs is either not estimated (as in the case of unpermitted CAFOs) or they contribute a very small share to overall loadings.[1]

---

[1] Data from the Chesapeake Bay Program’s ChesapeakeStat (https://stat.chesapeakebay.net/?q=node/130&quicktabs_10=1) suggest that, in 2013, the percentage of nitrogen loadings to the Chesapeake Bay watershed from regulated agricultural sources was 0.7 percent, and that of phosphorus loadings was 2.1 percent. Note that these just include point-source loadings from permitted CAFOs and exclude nonpoint-source loadings from any CAFOs as well as point-source loadings from unpermitted CAFOs. The Chesapeake Bay Program is a regional partnership, made up of Federal and State agencies, local governments, nonprofit organizations, and academic institutions, which leads and directs bay restoration and protection.

livestock operations that confine animals for a minimum number of 45 days per year. Because of this production style, they often gather manure mixed with urine and water in holding tanks or ponds; this collected product is spread on surrounding crops or fields to fertilize crops or as a soil amendment to promote plant growth. AFOs are also characterized by size; roughly, those with less than 300 animal units[3] are considered “small,” those with between 300 and 999 animal units are considered “medium,” and those with more than 1,000 are considered “large.” Based on size and/or discharges, certain AFOs may be characterized by the pertinent regulatory authority as concentrated animal feeding operations (CAFOs), which may need to obtain NPDES permits to operate. The permits require specific manure-management practices intended to contain manure-storage leaks (point-source discharges) as well as runoff from fields (nonpoint-source discharges). The portions of

---

[3] An “animal unit” is a method of normalizing across animal types and sizes. Each animal unit represents approximately 1,000 pounds of average live weight.

State TMDL implementation plans concerning CAFOs have generally focused on greater monitoring and enforcement of already adopted regulations. However, the ability of these regulations to reduce discharges has come into question, based on poor performance and lack of enforcement (Centner, 2003; GAO, 2003; USDA-NRCS, 2011; Perez, 2011; NRDC, 1998).

The CAFO regulations also do not address certain discharges from CAFOs or those from unregulated AFOs. While regulatory authorities and farm-service agencies may encourage unregulated AFOs to voluntarily use manure in an agronomic fashion to avoid runoff, many are not required to do so. Research suggests that producers often do not adopt these practices even when it would be efficient to do so (USDA-NRCS, 2011; USDA-NRCS, 2013). Because of these reasons, current strategies to address manure-related runoff have not yielded the discharge reductions desired. Meeting TMDL agricultural-discharge reduction from AFOs may therefore require other policy instruments.

Nutrient trading programs can facilitate reductions in agricultural runoff and lower regulated point sources' costs of pollution control. Trades occur when entities with high discharge-reduction costs pay low-cost dischargers to reduce pollution. As pollution discharge reduction costs at agricultural operations are estimated to be lower per unit than those at wastewater treatment facilities, nutrient trading programs generally posit agricultural operations as sellers of nutrient "credits,"[4] with wastewater treatment facilities as buyers (Chesapeake Bay Commission, 2012). However, before selling credits, an agricultural producer must meet "baseline" requirements, which entail lowering discharges below business as usual. Once they have met these baseline requirements, they can reduce discharges further and sell representations of these reductions as credits. The discharge reductions of meeting the baseline help to meet TMDL agricultural-loading reductions. The credits sold represent loading reductions attributed to point sources. Because regulated point sources can ostensibly purchase credits for lower costs than technological improvements, they can achieve their loading reductions at lower cost.

The research on nutrient trading programs generally focuses on reductions of nutrient loadings from crop-only operations (e.g., Ribaudo et al., 2014; Ribaudo and Gottlieb, 2011). This leaves unanswered questions regarding livestock-operation participation in nutrient trading and overlooks pertinent questions regarding differences between crop-only and livestock producers:

- CAFOs have both nonpoint- and point-source discharges (see box, "Point and Nonpoint-Source Pollution"). As such, would they be buyers or sellers of credits? Could they reduce their discharges from their nonpoint sources and use it to satisfy their point-source discharge reduction requirements?
- Since satisfying regulations is required to meet the baseline, how might CAFO regulations change livestock operations' participation in nutrient trading? Would the cost of satisfying regulations hinder their entry into nutrient trading?
- Do reductions in manure have different costs than commercial fertilizer applications, and if so, will this impact the ability of different types of agricultural producers to generate credits? While farmers just applying commercial fertilizer may reduce costs if they reduce such appli-

---

[4] For simplicity, 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 (like agricultural producers) and sold to regulated entities (like wastewater treatment facilities), and "credits," which are bought and sold between regulated entitles. Both types of obligations are purchased so that regulated entities can meet their discharge limits.

cations, those generating manure may need to ship it offsite to reduce applications, resulting in cost increases.

- How would the fact that AFOs have less cropland impact their ability to generate credits from reduction in nutrients to cropland?

Due to these differences, an examination of how livestock operations' potential differences from crop-only producers in nutrient trading is warranted to assess such programs' usefulness in reducing discharges from these entities. For details on how this report relates to the June 2014 report, *An Economic Assessment of Policy Options To Reduce Agricultural Pollutants in the Chesapeake Bay,* see box, "Comparing Economic Research Service Reports Focus on Agriculture and the Chesapeake Bay."

Comparing ERS Reports on Agriculture and the Chesapeake Bay

In June 2014, the Economic Research Service published *An Economic Assessment of Policy Options To Reduce Agricultural Pollutants in the Chesapeake Bay*," by Marc Ribaudo, Jeffrey Savage, and Marcel Aillery (ERR-166). The report, which explored policy solutions to agricultural pollution in the Chesapeake Bay, was broken into three sections:

1. The authors analyzed crop-level data to estimate the costs of implementing different policies to meet the load reduction required under the Chesapeake Bay total maximum daily load (TMDL). They modeled several scenarios in which farm operators can choose among practices to reduce agricultural loadings to the Chesapeake Bay.
2. Using this same crop-level data, the authors examined how baseline requirements for nutrient trading influence participation in such a program and the generation and price of tradable credits.
3. The authors modeled manure flows and costs of manure shipping within the Chesapeake Bay watershed, given different farmer levels of willingness to accept manure.

The 2014 report indicated the importance of targeting policies to operations that were more likely to pollute and emphasized the utility of leveraging markets for pollution reductions. Our report and the earlier one share a regional focus and both explore issues related to nutrient trading and manure management. This report builds on findings from the 2014 one, and provides a more detailed examination of complexities involved in farm type, adding a number of elements to the analysis of policy options to reduce Chesapeake Bay agricultural nutrient loadings, such as:

1. Providing a more extensive and updated picture of manure nutrient generation and livestock agriculture in the Chesapeake Bay watershed.
2. Focusing on farm-level features. In the case of livestock producers' participation in nutrient trading, farm-level features play important roles in operations' ability to meet nutrient trading baselines. The earlier report used the acre as the unit of analysis in the report's nutrient trading section. Farmers can adopt management practices for these individual acres, but each acre is treated in isolation from the farm it is on.
3. Considering how implementation of nutrient management may differ between producers that do and do not generate manure, in the context of reaching baseline requirements for nutrient trading.

Agriculture and Nutrient Discharge in the Chesapeake Bay

Chesapeake Bay agricultural nutrient pollution

Two of the main pollutants of concern in the Chesapeake Bay are the nutrients nitrogen and phosphorus. While these nutrients are beneficial to agriculture, landscaping, ecosystems, and land-based production, they can cause problems if they are present in excess levels. Increased nitrogen and phosphorus in surface water can lead to algae blooms, reducing the amount of oxygen in water and impacting fish and other aquatic life. Some types of algal blooms can also be toxic, leading to public health concerns.

Agricultural runoff is a significant contributor to Chesapeake Bay nutrient loadings. The EPA estimates that all forms of agriculture are responsible for at least 39 percent of nitrogen and 57 percent of phosphorus loadings to the Chesapeake Bay. In 2012, land application of livestock manure accounted for 15 percent of that nitrogen and 37 percent of those phosphorus loadings (or 38 percent and 74 percent of the "all forms of agriculture" nitrogen and phosphorus loadings) (figs. 1 and 2).

Nutrients are beneficial for crop growth and are a natural byproduct of livestock production. In a traditional farm setting that incorporates crop and livestock production, nutrients are removed from the soil by plants, which are fed to livestock. The livestock then replenish the soil nutrients with manure. The nutrient balance breaks down if there are not enough nutrients to replenish the soil, or if more nutrients are produced than can be used by the plants and soil.

Farms may generate more nutrients than they can assimilate when they have too many animals and not enough land. Farms increasingly specialize in either crop or livestock production, hence farm-level nutrient production may not match farm-level nutrient needs (Kellogg et al., 2000). Certain types of livestock agriculture have also become more geographically concentrated, occasionally in regions distant from the locus of crop production. Thus, nutrient balance can be disrupted at a regional as well as a farm level. In part because of these influences, manure is no longer heavily used as a fertilizer; for example, between 2003 and 2006, only 10 percent of U.S. acreage planted with 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.

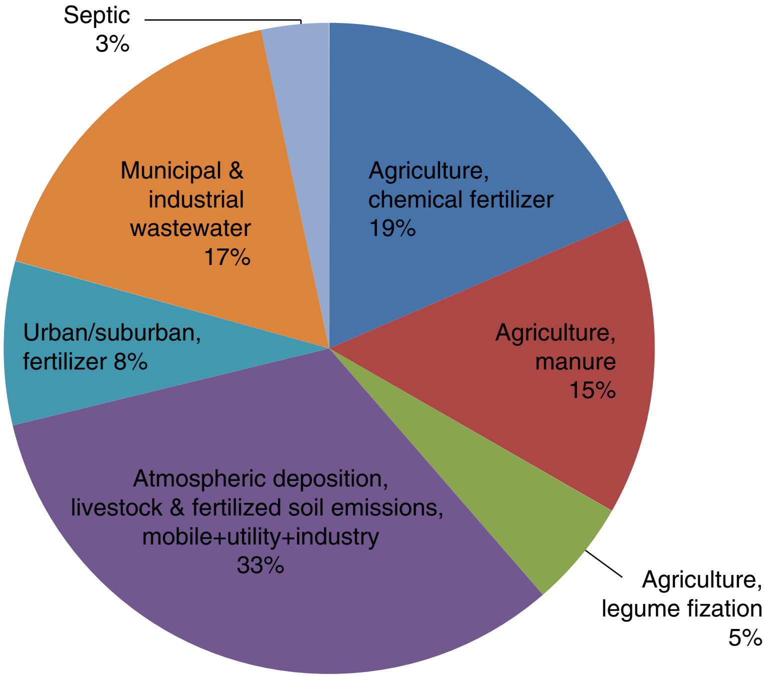
When more manure nutrients are produced than can be assimilated on the farm or the region, they may be over-applied to land, leading to nutrient runoff.[5] To avoid over-application, livestock growers with less land than needed may ship manure to other locations or adopt a number of other practices. However, transporting manure off-farm is expensive and other farmers' willingness to pay for or even accept manure for free is often very 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 above agronomically appropriate rates (Sheriff, 2005).

---

[5] For simplicity, we use the phrase "manure nutrients" to refer to nutrients contained in both manure from hogs, cattle, and other animals, as well as litter from poultry.

Figure 1

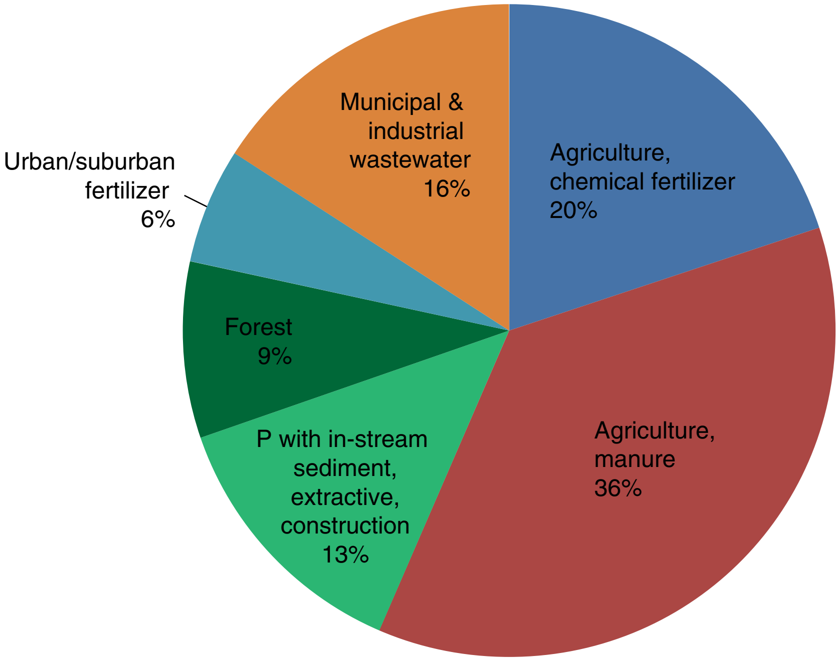
Sources of nitrogen loadings to the Chesapeake Bay, 2012



Note: Table use of rice.
Source: U.S. Environmental Protection Agency, Chesapeake Bay Program, personal communication from Jeff Sweeney, Integrated Analysis Coordinator, March 2014a.

Figure 2

Sources of phosphorus loadings to the Chesapeake Bay, 2012



Source: U.S. Environmental Protection Agency, Chesapeake Bay Program, personal communication from Jeff Sweeney, Integrated Analysis Coordinator, March 2014a.

Nutrient pollution can also arise from livestock production facilities via a more direct method than runoff from fields. Livestock production has increasingly moved to very large-scale confinement operations with thousands of animals. Much of the manure generated at these operations is scraped or flushed from animal-production areas into storage facilities, including manmade earthen ponds, concrete or steel tanks, and manure piles. Many of the pollution discharges from livestock operations reported in the media occur when such storage facilities leak or overflow (e.g., Goldberg, 2007; Wilson, 2008; Virkler, 2005).

These trends in excess manure nutrients have been an ongoing problem in the Chesapeake Bay area. Using 2007 Census of Agriculture data, Ribaudo and colleagues (2014) found several county clusters within the Chesapeake Bay States that generate high amounts of recoverable manure per acre of spreadable land. Earlier research finds similar Chesapeake Bay watershed "manure hot spots" in the Shenandoah Valley, the Delmarva[6] Peninsula, and Lancaster County, Pennsylvania (Chesapeake Bay Foundation, 2004; Kellogg et al., 2000).

Overview of Chesapeake Bay agricultural land use and manure nutrient generation

The 2012 Census of Agriculture tallies just over 105,000 farms[7] in the Chesapeake Bay counties, with over 12 million acres of crop and pasture land (72 percent of which is devoted to cropland and the other 28 percent to pasture) (table 1). This agricultural land can agronomically assimilate over 1.6 billion pounds (lb) of nitrogen and 204 million lb of phosphorus.[8] Manure is applied to 17 percent of this crop and pasture land, while fertilizer is applied to 42 percent of it.[9]

Figures 3 and 4 show how much nitrogen and phosphorus each county in the Chesapeake Bay watershed can agronomically assimilate via crops and pasture. The counties with the highest "uptake capacities" are similar for nitrogen and phosphorus, as plants need both to grow. Areas with the highest uptake capacities include the Bay counties in New York, Pennsylvania, Delaware, and parts of Maryland.

Nearly two-thirds of the nearly 3.8 million animal units in the Bay are raised in confinement,[10] yielding 234 million lb of recoverable manure nitrogen and nearly 106 million lb of recoverable

---

[6] "Delmarva" is short-hand for "Delaware-Maryland-Virginia."

[7] According to the USDA's National Agricultural Statistics Service, the agency that administers the Census of Agriculture, a "farm" is any place from which $1,000 worth of agricultural products could be or is sold. Thus, a "farm" can refer to operations even with very little farm output; approximately a quarter of farms in the Chesapeake Bay have $1,000 or less in their total value of production.

[8] Assimilative capacity is estimated using reported crop yields in 21 commodities as well as assumed uptake capacities for two pasture acreage types. Roughly, the amount that can be assimilated for a commodity is estimated as the reported crop yield multiplied by a nutrient uptake factor and a factor allowing for the fact that not all nutrients applied can be used. See appendixes D and E for further details.

[9] The amount of manure-applied acres arises from the 2012 Census of Agriculture question on the number of crop or pasture acres to which manure is applied. Due to the question's wording, it is not possible to distinguish what percentage of these acres is cropland versus pastureland. Prior research examining manure application just to crop acreage suggests that manure was applied to just 10 percent of cropland in eight major crops across the United States in 2006 (Ribaudo et al., 2011). The difference may arise due to a high percentage of manure-applied pastured acreage, an increase in manure applications over time, or differences by region.

[10] Roughly, the number of animal units is estimated using the number of animals reported in inventory and the number sold or removed to predict the average number of animals at the operation over the course of a year. This is multiplied by a factor to denote average pounds of live weight per head. Confinement is predicted using the type of animal as well as the ratio of animals to pasture acreage. See appendix A for further details.

Table 1

Total farms, animal units, land use acreage, and nutrients, Chesapeake Bay agricultural operations, 2012

Farms	105,188
Animal units[1]	3,781,763
Pastured	1,419,390
Confined	2,353,678
Crop and pasture acreage	12,336,432
Fertilized crop and pasture acreage	5,133,858
Manure-applied crop and pasture acreage	2,086,513
Nitrogen assimilative capacity (lb)	1,655,121,236
Phosphorus assimilative capacity (lb)	204,136,044
Recoverable manure nitrogen produced (lb)	234,488,615
Recoverable manure phosphorus produced (lb)	105,719,955
Total onfarm excess recoverable nitrogen (lb)	107,529,715
Total onfarm excess recoverable phosphorus (lb)	63,583,035

[1] An "animal unit" is a method of normalizing across different animal types and sizes. Roughly, one animal unit is equal to 1,000 lb of live weight.

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

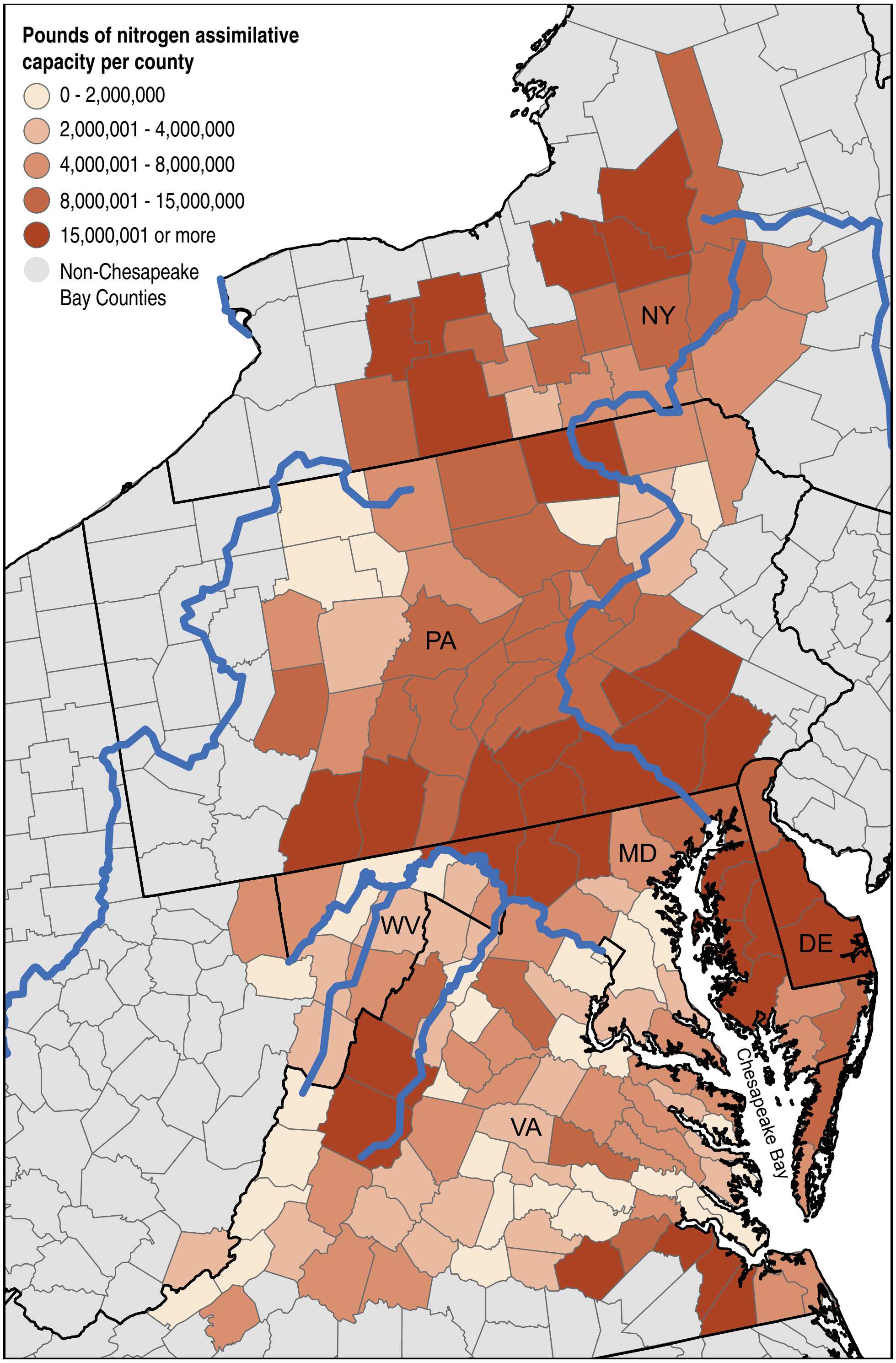
manure phosphorus. "Recoverable" in this scenario refers to the ability to capture the manure nutrients and later apply them to land. Operations without confined livestock are assumed to not produce any recoverable manure nutrients, as their manure management methods generally do not lend themselves to collecting wastes. Fertilizer is not considered recoverable; hence, operations that produce no livestock do not generate recoverable nutrients. Manure at pasture-based operations is assumed to be deposited directly on the land versus being collected for later application; thus, pasture-based operations are also assumed to not produce any recoverable nutrients.

About a third of the estimated nitrogen and just over half of the estimated phosphorus excreted by animals in the Chesapeake Bay watershed can be recovered for later use (figs. 5 and 6). While nearly 90 percent of the manure nitrogen is excreted by animals at AFOs, a significant portion of this cannot be recovered; it is lost in storage, transportation, and atmospheric volatilization. Twelve percent of manure nitrogen is produced at non-AFOs like pasture-based operations. About 85 percent of manure phosphorus is produced on AFOs, but a greater fraction of this can be recovered; phosphorus also is not lost to volatilization. Only 16 percent of manure phosphorus is produced by animals at non-AFOs.

This recoverable nitrogen and phosphorus is largely generated in the Chesapeake Bay counties in New York, Pennsylvania, and Delaware (figs. 7 and 8). Maryland's Eastern Shore and Virginia's eastern edge in the Bay watershed are also places with relatively higher levels of recoverable manure nutrient production.

Figure 3

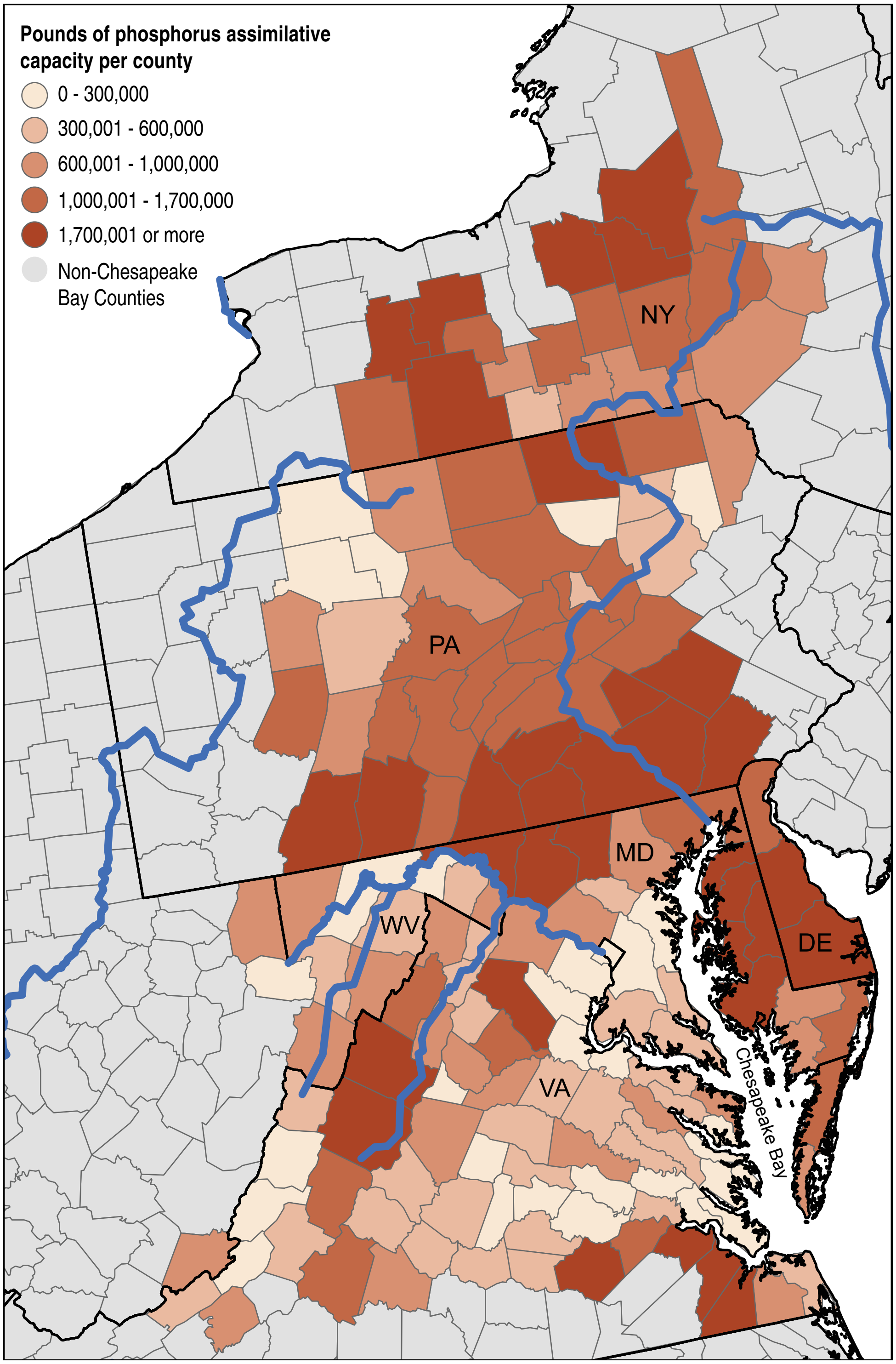
Nitrogen assimilative capacity on cropland and pastureland, Chesapeake Bay watershed counties, 2012



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

Figure 4

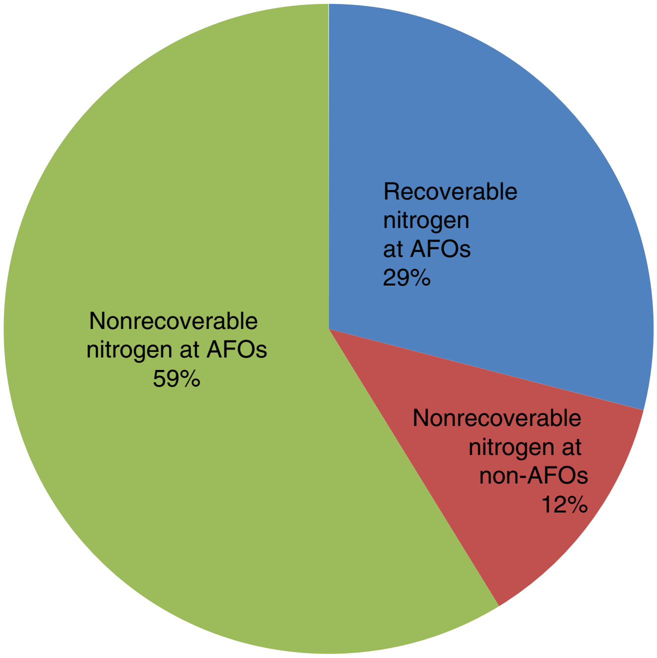
Phosphorus assimilative capacity on cropland and pastureland, Chesapeake Bay watershed counties, 2012



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

Figure 5

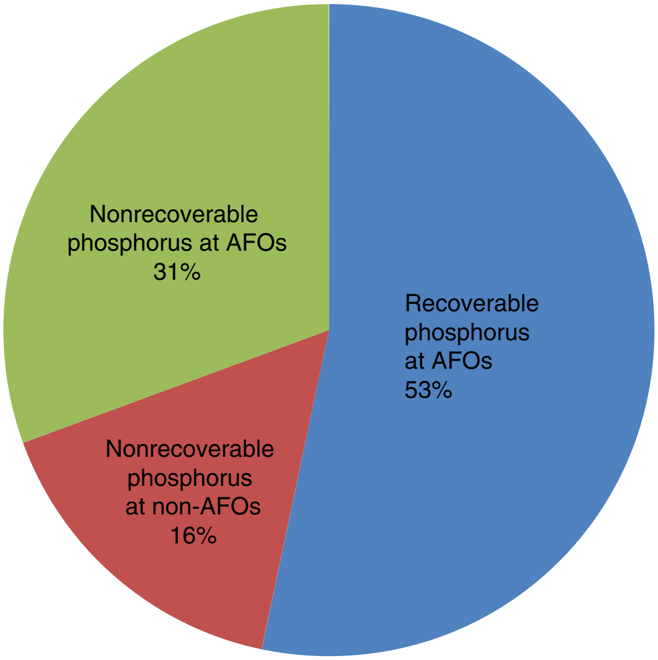
Manure nitrogen excreted by livestock in the Chesapeake Bay, by AFO status and recoverability, 2012



AFO = animal feeding operation.
Source: USDA, Economic Research Service calculations based on USDA, National Agricultural Statistics Service, 2012 Census of Agriculture.

Figure 6

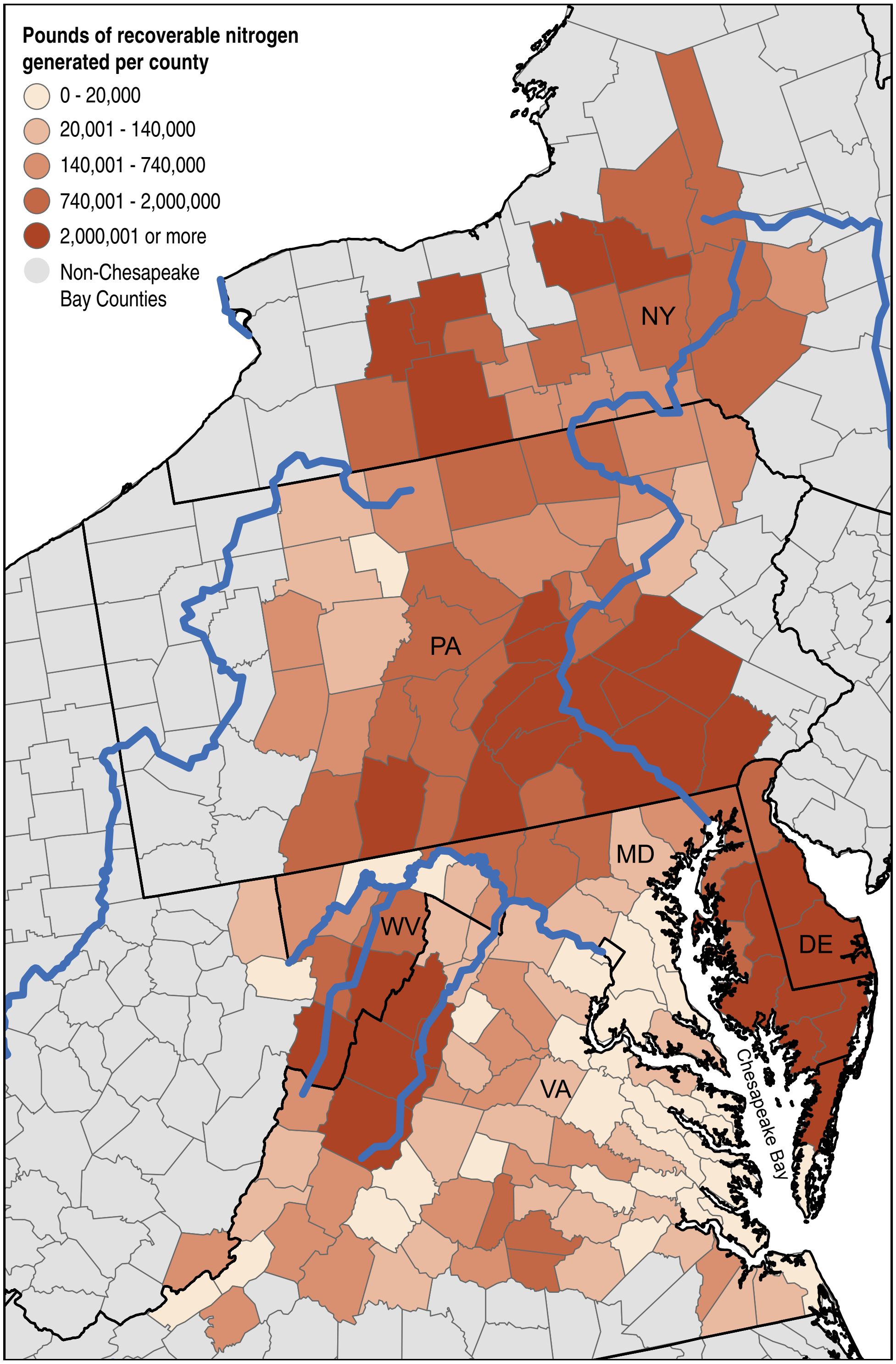
Manure phosphorus excreted by livestock in the Chesapeake Bay, by AFO status and recoverability, 2012



AFO = animal feeding operation.
Source: USDA, Economic Research Service calculations based on USDA, National Agricultural Statistics Service, 2012 Census of Agriculture.

Figure 7

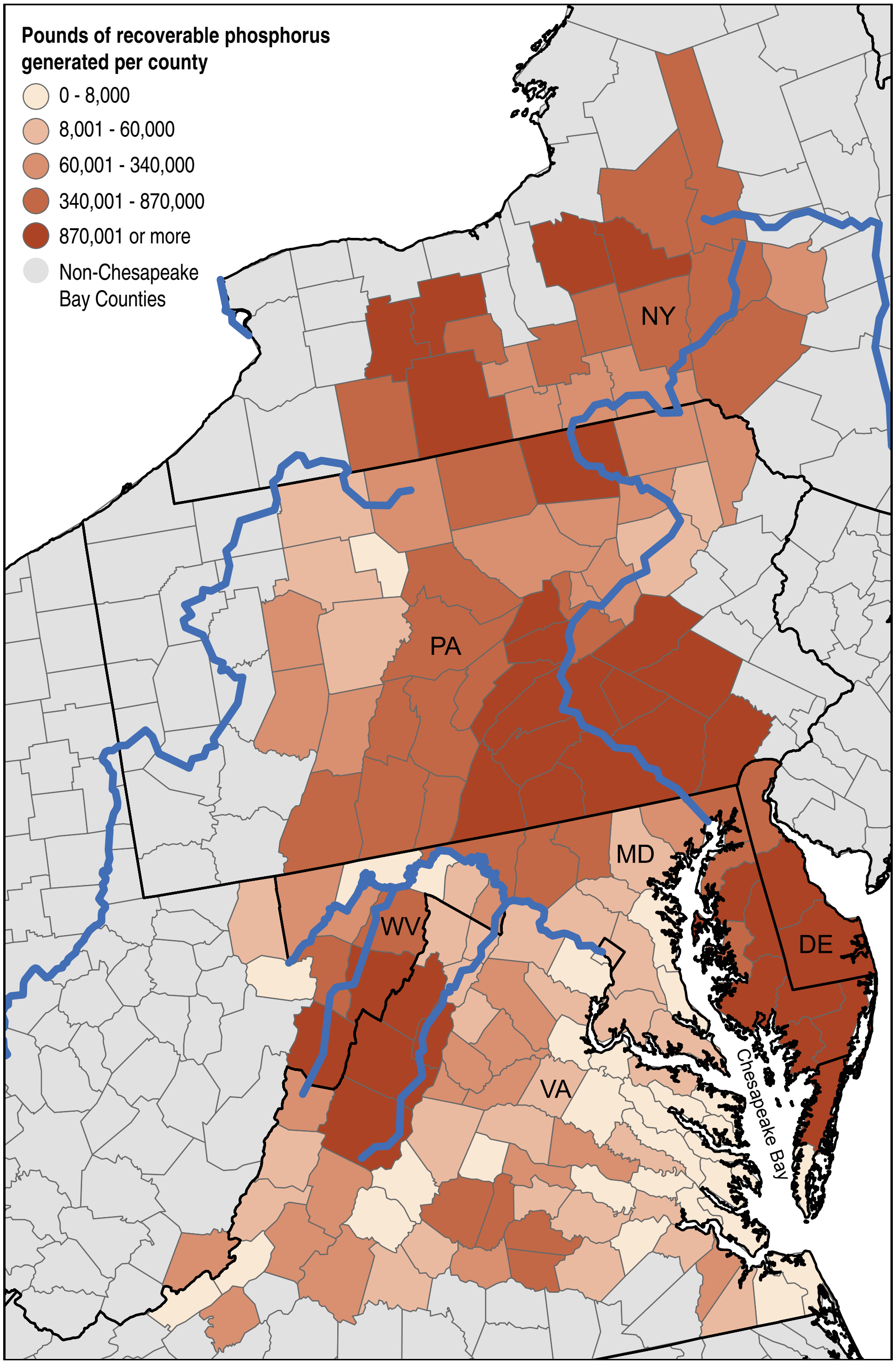
Recoverable manure nitrogen generation, Chesapeake Bay watershed counties, 2012



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

Figure 8

Recoverable manure phosphorus generation, Chesapeake Bay watershed counties, 2012



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

Because the total amounts of recoverable manure nutrients generated are less than the amounts that can be assimilated on cropland or pastureland (see table 1), conceivably all recoverable manure nutrients generated in the Bay could be used there. However, this could only be the case if manure served as a perfect replacement for commercial fertilizer and if there were no cost associated with transporting it from the place it was generated to the place it could be used. Due to differences in nutrient consistency, ease of handling, and ability to control nutrient losses, manure nutrients are not a perfect substitute for commercial fertilizer (Ribaudo et al., 2011). Additionally, the high cost of transporting manure relative to the value of the nutrients in manure can be prohibitive to its use.

While the nutrient balance at the watershed level suggests that all manure nutrients could be used there, the farm level suggests a different story. Forty-six percent of recoverable-manure nitrogen and 60 percent of recoverable-manure phosphorus in the Bay are generated at operations that cannot use those substances in an agronomic fashion. At these operations, the amount of manure nutrients produced is greater than the amount that can be used by crops or pasture.

What types of livestock are produced in the Bay region? We characterize farms with livestock according to type of animal and the animal's pastured or confined status (see appendix A for defining whether certain animal types are pastured or confined). While 54 percent of farms in the Chesapeake Bay watershed have pastured animals, 62 percent of animals are confined (table 2). Nearly a third of the Bay's animals (by live weight) are confined dairy cows, with another 20 percent being confined poultry. Approximately a quarter of the livestock are pastured beef cattle types. Dairy cows and poultry constitute the largest portion of confined livestock in the Bay watershed area (52 and 33 percent, respectively).

Table 2

Livestock production in the Chesapeake Bay area, 2012

	Percentage of farms with type of livestock	Average number of animal units by operation[1]	Percentage of all animal units in region	Percentage of confined animal units in region
Confined	33.7	66	62.2	100.0
Beef cattle[2]	4.9	31	4.2	6.8
Dairy cows[3]	10.3	112	32.1	51.5
Swine	4.5	38	4.8	7.6
Poultry	18.9	39	20.5	32.9
Donkeys, sheep, goats, and horses	4.1	6	0.7	1.1
Pastured	53.8	25	37.5	0.0
Beef cattle[4]	26.0	34	24.5	0.0
Dairy cows[5]	8.8	25	6.2	0.0
Donkeys, sheep, goats, and horses	31.0	8	6.9	0.0
Specialty livestock[6]	3.0	3	0.2	0.0

Note: An "animal unit" is a method of normalizing across animal types and sizes. One animal unit is roughly equal to 1,000 lb live weight. See appendix A for further explanation of calculating animal units.

[1] Averages for farms that have any of the specific animal type. [2] Includes fattened cattle, veal, confined beef calves, confined beef heifers, confined beef steer, and confined beef breeder cows. [3] Includes dairy cows, confined dairy calves, confined dairy heifers, and confined dairy steer. [4] Includes pastured beef calves, pastured beef heifers, pastured beef steer, and pastured beef breeder cows. [5] Includes pastured dairy calves, pastured dairy heifers, and pastured dairy steer. [6] Includes bison, deer, elk, llama, mink, rabbit, emu, geese, ostriches, pheasant, pigeons, and quail.

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

Dairy cows and poultry operations are concentrated in different portions of the Chesapeake Bay watershed. Figure 9 shows the counties in the Chesapeake Bay watershed as well as the relative number of dairy animal units, while figure 10 shows the relative number of poultry animal units. Most dairy cows and heifers are in New York and Pennsylvania, while poultry are concentrated in Delaware, the Eastern Shore of Maryland, portions of western Virginia, and southern Pennsylvania.

The type of livestock varies with the size of the operation and the level of animal confinement. Size classes are defined by EPA regulations.[11] Large and medium AFOs are most likely to have poultry, while small AFOs are most likely to have dairy cows (table 3). Note that livestock operations may

Table 3

Percentage of operations with different types of livestock and average number of animal units, by type of operation, Chesapeake Bay counties, 2012

	Percent of operations with type of animal								
	Confined					Pastured			
	Beef cattle[1]	Dairy cows[2]	Swine	Poultry	Donkeys, sheep, goats, and horses	Beef cattle[3]	Dairy cows[4]	Donkeys, sheep, goats, and horses	Specialty livestock[5]
Some livestock but not likely to be confined	4	3	6	26	6	46	2	53	5
Small AFOs	20	71	6	28	9	11	61	27	2
Medium AFOs	8	23	12	73	3	18	17	10	1
Large AFOs	8	20	17	73	4	19	14	12	0
	Average number of animal units, operations with type of animal unit								
	Confined					Pastured			
	Beef cattle[1]	Dairy cows[2]	Swine	Poultry	Donkeys, sheep, goats, and horses	Beef cattle[2]	Dairy cows[3]	Donkeys, sheep, goats, and horses	Specialty livestock[5]
Some livestock but not likely to be confined	7	3	2	0.2	4	31	3	8	3
Small AFOs	48	88	40	26	11	57	22	7	1
Medium AFOs	97	433	229	210	6	85	93	7	2
Large AFOs	142	1,495	697	612	3	114	247	5	2

AFOs = animal feeding operations.

Note: Four percent of operations have some livestock that are not likely to be confined and have confined fattened cattle and veal calves. Rows do not sum to 100 percent because farms can have more than one type of livestock.

[1] Includes fattened cattle, veal, confined beef calves, confined beef heifers, confined beef steer, and confined beef breeder cows. [2] Includes dairy cows, confined dairy calves, confined dairy heifers, and confined dairy steer. [3] Includes pastured beef calves, pastured beef heifers, pastured beef steer, and pastured beef breeder cows. [4] Includes pastured dairy calves, pastured dairy heifers, and pastured dairy steer. [5] Includes bison, deer, elk, llama, mink, rabbit, emu, geese, ostriches, pheasant, pigeons, and quail.

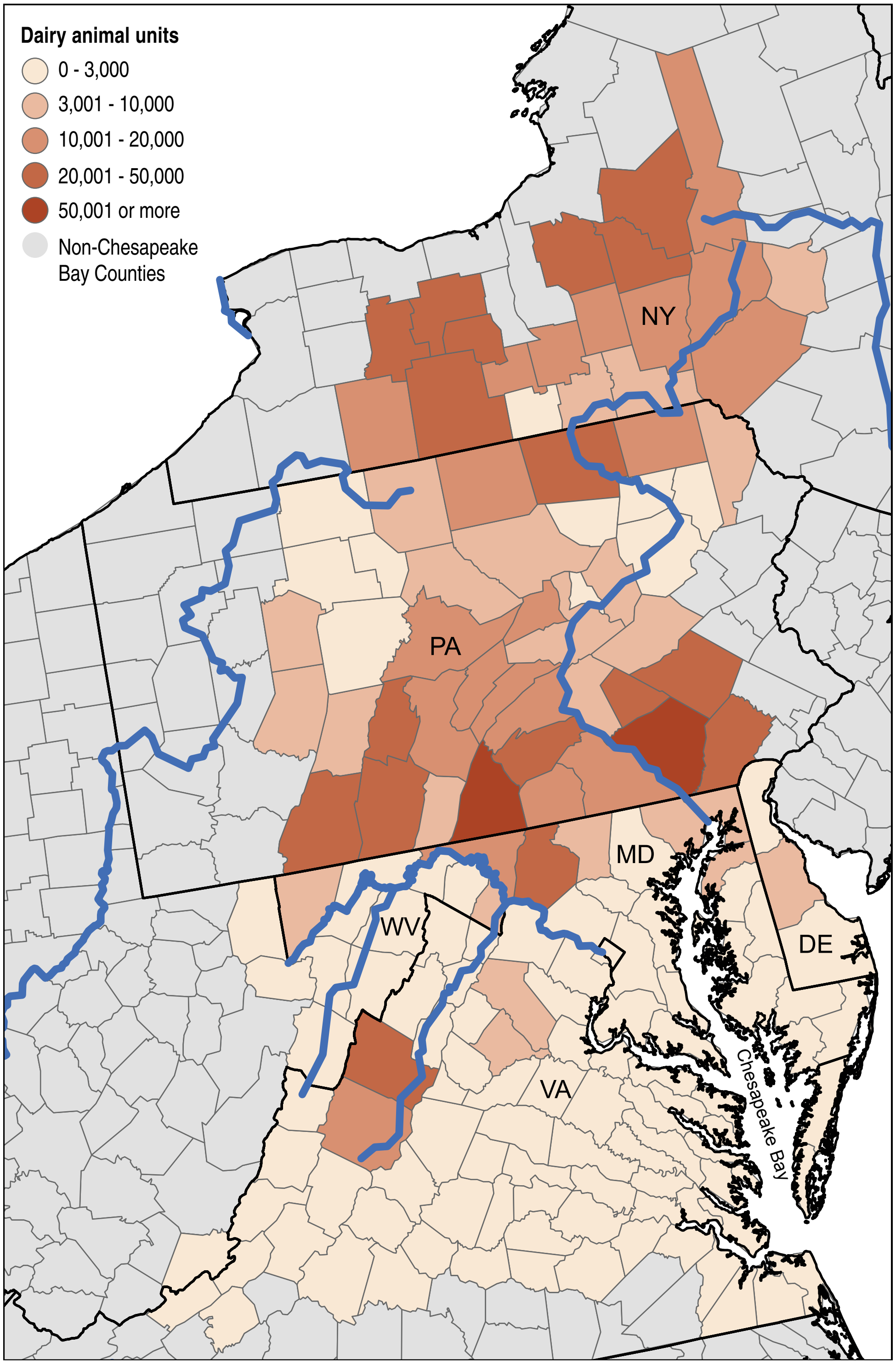
Source: USDA, Economic Research Service calculations based on USDA, National Agricultural Statistics Service, 2012 Census of Agriculture.

---

[11] See appendixes A, B, and C and the later subsection "Federal Clean Water Act Concentrated Animal Feeding Rules."

Figure 9

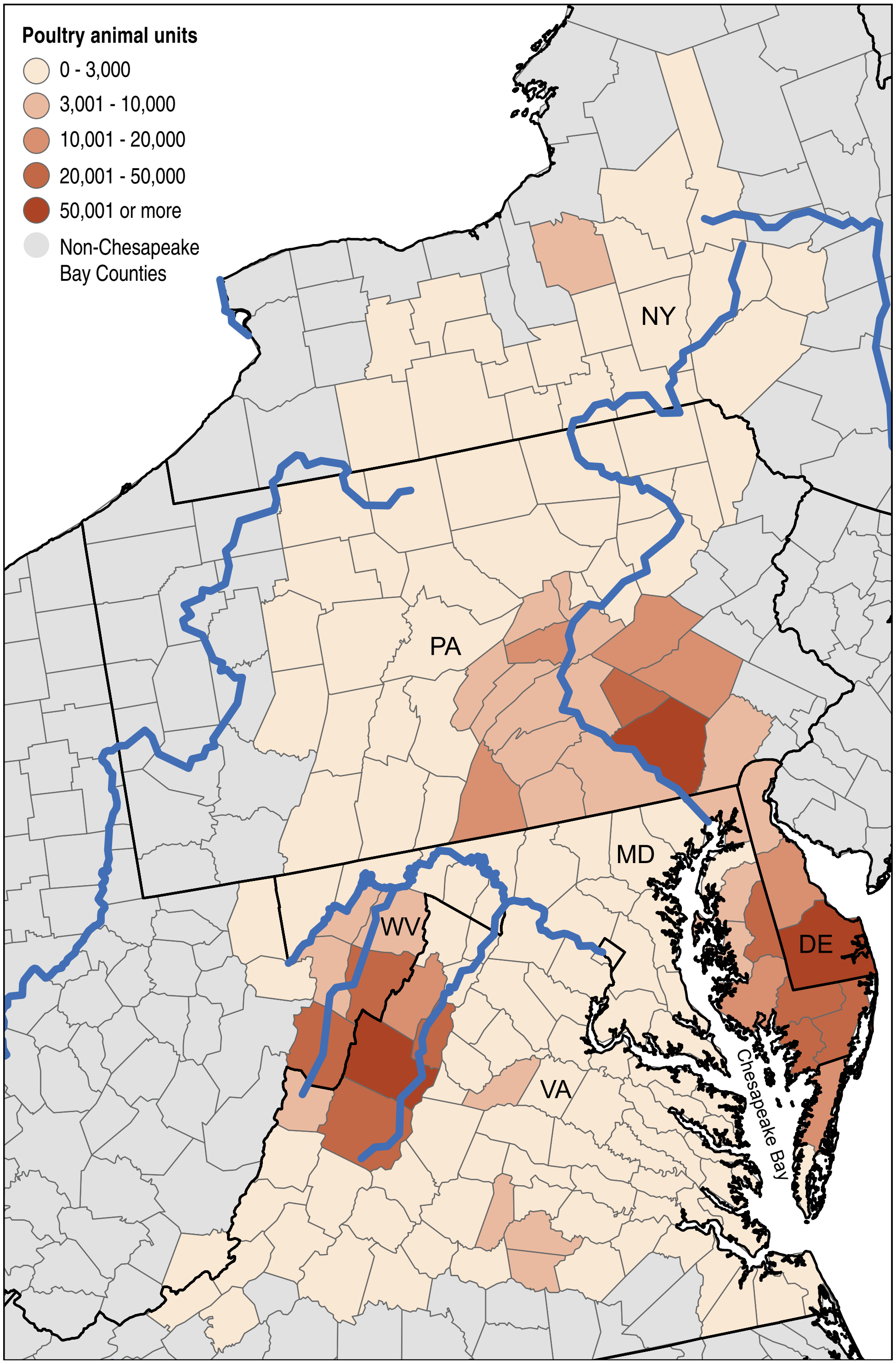
Number of dairy animal units, by county, in the Chesapeake Bay watershed counties, 2012



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

Figure 10

Number of poultry animal units, by county, in the Chesapeake Bay watershed counties, 2012



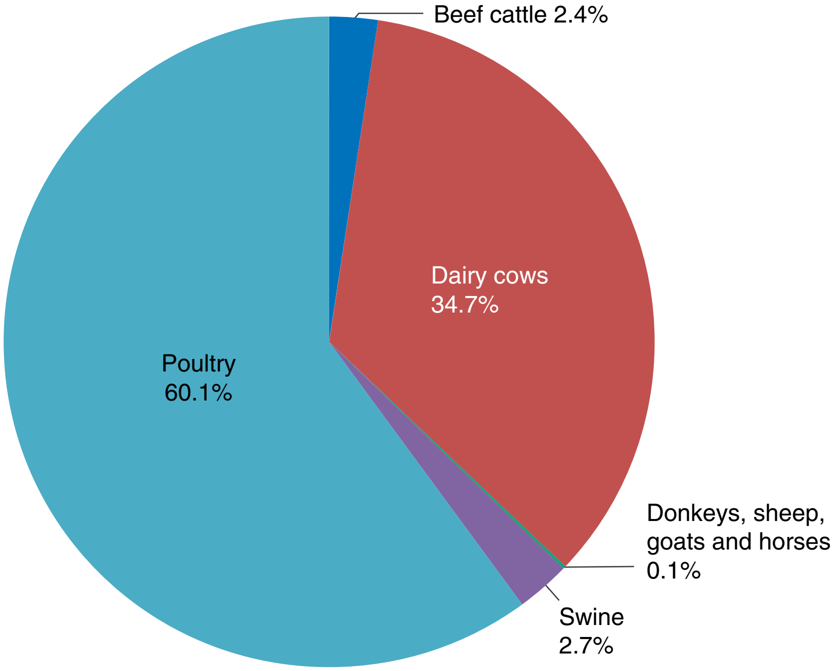
Source: USDA, Economic Research Service calculations based on USDA, National Agricultural Statistics Service, 2012 Census of Agriculture.

have more than one animal type. To translate some of the animal units into number of head, the average large poultry AFO in the Bay area has approximately 230,000 birds in inventory, while the average large dairy AFO has about 950 cows and heifers that have calved. Small and medium dairy AFOs have about 115 and 290 cows, respectively. Small and medium poultry AFOs have about 10,000 and 80,000 birds, respectively.

Because they constitute the largest shares of confined livestock in the Bay area, dairy cows and poultry also contribute the largest shares of recoverable manure nutrients. Dairy cows contribute an estimated third (35 percent) of the recoverable manure nitrogen in the Chesapeake Bay watershed (fig. 11). Poultry generate an estimated 60 percent, with the other livestock types contributing far less. These percentages are similar for phosphorus (fig. 12).

Figure 11

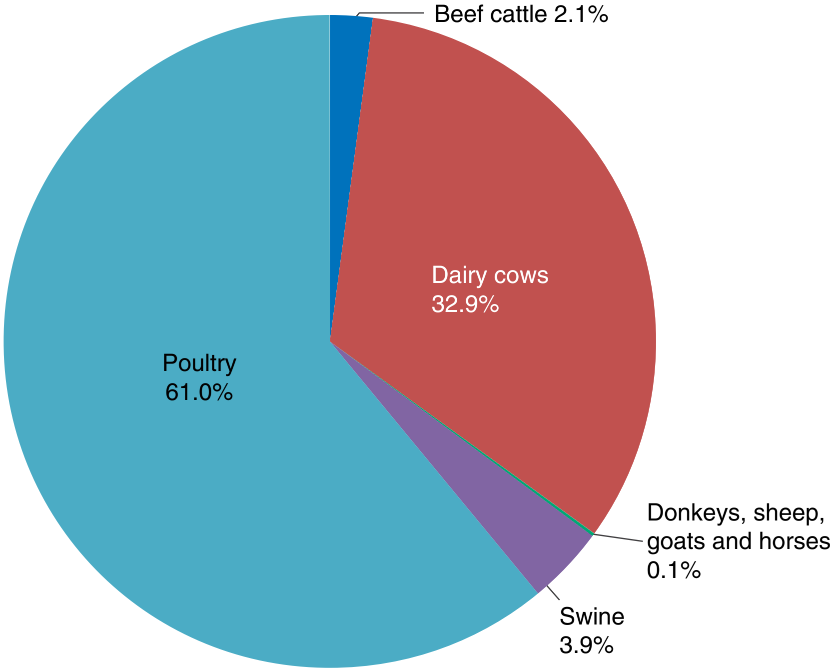
Recoverable manure nitrogen generation, by animal type, Chesapeake Bay, 2012



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

Figure 12

Recoverable manure phosphorus generation, by animal type, Chesapeake Bay, 2012



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

Manure and fertilizer application by type of Chesapeake Bay agricultural operation

Increasing specialization in agricultural production has yielded operations that focus on specific types of production. Roughly, these can be divided into crop versus livestock production. Table 4 shows Chesapeake Bay agricultural operations by size and crop versus livestock specialization. AFOs constitute 15 percent of the farms in the Chesapeake Bay region in 2012. Pasture operations constitute approximately half of farms, while crop farms with less than 100 acres of cropland make up about a quarter. The remainder is in crop farms with more than 100 acres of cropland. Despite constituting a relatively small percentage of farms in the Bay watershed, large crop farms and small AFOs each cover about a fifth of the crop and pasture acreage. Operations with unconfined livestock have the largest share of crop and pasture acreage, largely because of pastureland.

AFOs cover a large and disproportionate share of manure acreage in the Chesapeake Bay watershed. Although they constitute only 15 percent of all agricultural operations and cover only 30 percent of crop and pasture acreage, they control 63 percent of manure-applied acres in the region. Small and medium AFOs account for 56 percent of manure acreage. Interestingly, AFOs also manage 38 percent of fertilized crop and pasture acreage, an indication that they are not just replacing fertilizer with manure.

A primary concern related to excess manure nutrients is AFOs that have no land on which to apply manure. Most AFOs (92 percent) do have crop or pasture acreage, but the 8 percent with none will automatically have excess manure nutrients (see table 4). The percentage of AFOs with no land on which to spread manure increases with size; 22 percent of large AFOs in the Bay region have no crop or pasture acreage.

Table 4

Land use by type of Chesapeake Bay agricultural operation, 2012

		Percentage in region			Percentage of farms with any…		
Operations with...	Farms	Crop and pasture acreage	Manure-applied acreage	Fertilizer-applied acreage	Crop and pasture acreage	Manure-applied acreage	Fertilizer-applied acreage
				Percent			
All	**100**	**100**	**100**	**100**	**96**	**27**	**42**
No livestock -- less than 100 acres of cropland	27	8	2	4	95	9	33
No livestock -- 100 or more acres of cropland	6	23	11	35	100	22	78
Some livestock but not likely to be confined	52	39	23	23	97	27	35
All animal feeding operations (AFOs)	15	30	63	38	92	60	69
Small AFOs	12	20	41	24	95	65	73
Medium AFOs	2	7	15	10	81	44	53
Large AFOs	1	3	7	5	78	39	55

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

AFOs are more likely than other types of farms to apply manure, but not all of them do. Only 60 percent of AFOs report applying manure to cropland or pastureland, despite the fact that 92 percent of them have such land. A greater percentage (69 percent) reports applying fertilizer. What do the other 40 percent of AFOs do with their manure? Some operations (8 percent) have no agricultural land on which to apply manure. Others may ship all of their manure off-farm, although this practice is not widespread (Key et al., 2011; MacDonald et al., 2009; Ribaudo et al., 2003). Some operations may not have land suitable for manure application (Ribaudo et al., 2003). The numbers suggest that a significant portion of farms that generate manure nutrients do not use any of it onsite.

Even when operations apply manure, they apply it to less acreage than when they apply fertilizer. Table 5 shows the average number of crop or pasture acreage for farms with any such land. Farms that apply manure on average apply it to 49 percent of their land, but farms that apply fertilizer apply it to 61 percent of their land. While crop-only operations have higher percentages of fertilized than manure-applied land, rates for AFOs are roughly similar. AFOs apply manure to 59 percent and fertilizer to 66 percent of their land, while large crop-only farms that apply manure do so to only 40 percent of their land, and those that apply fertilizer do so to 72 percent of their land.

Table 5

Farms with any crop or pasture acreage, Chesapeake Bay operations, 2012 (averages by farm)

	All farms					Farms with any manure-applied acres			Farms with any fertilizer-applied acres		
	Crop or pasture acres[1]	Manure-applied acres[2]	Manure-applied acreage/ crop and pasture acreage[2]	Fertilizer-applied acres[3]	Fertilized crop and pasture acreage/ crop and pasture acreage[3]	Crop or pasture acres	Manure-applied acres	Manure-applied acreage/ crop and pasture acreage	Crop or pasture acres	Fertilizer-applied acres	Fertilized crop and pasture acreage/ crop and pasture acreage
All	**122**	**23**	**0.15**	**60**	**0.29**	**181**	**74**	**0.49**	**205**	**124**	**0.61**
No livestock -- Less than 100 acres of cropland	37	2	0.06	10	0.27	42	19	0.54	40	24	0.69
No livestock -- 100 or more acres of cropland	445	39	0.10	321	0.59	450	164	0.40	515	391	0.72
Some livestock but not likely to be confined	90	10	0.13	26	0.21	117	33	0.43	145	65	0.53
All animal feeding operations (AFOs)	263	99	0.41	157	0.51	282	141	0.59	282	179	0.66
Small AFOs	213	79	0.43	120	0.51	227	109	0.59	247	148	0.63
Medium AFOs	410	155	0.37	267	0.48	504	267	0.63	574	377	0.68
Large AFOs	797	332	0.34	562	0.53	1,024	617	0.63	1,059	736	0.69

[1] Farms with any crop or pasture acreage. [2] Farms with non-missing values of manure-applied acreage and non-zero values for crop or pasture acreage. Approximately 8.7% of farms with any crop or pasture acreage have missing values for manure-applied acreage. [3] Farms with non-missing values of fertilizer-applied acreage and non-zero values for crop or pasture acreage. Approximately 8.7% of farms with any crop or pasture acreage have missing values for fertilizer-applied acreage.

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

Nutrient uptake and manure nutrient generation by type of Chesapeake Bay agricultural operation

A further understanding of the relative pollution from AFOs comes from the estimated amount of recoverable manure nutrients generated at each farm and the amount of nitrogen and phosphorus that could be applied without nutrient buildup at each farm, given crop yields (the assimilative capacity). While AFOs constitute 42 percent of estimated nitrogen and 39 percent of the estimated phosphorus uptake capacity, they generate all of the recoverable manure nutrients (by assumption) (table 6).

Examination of the average practices at AFOs provides an indication of the relative amounts of nutrients produced via manure compared to onfarm assimilative capacity. Across all AFOs, the average assimilative capacity for nitrogen is greater than the average amount produced (44,913 lb versus 15,182 lb) (table 7). However, 10 percent of operations have no assimilative capacity, largely because these operations have no crop or pasture acreage. Comparison of the averages also hides the fact that 26 percent of AFOs generate more manure nitrogen than they can assimilate on their land. These percentages increase with the size of an AFO, such that over two-thirds of large AFOs have excess manure nitrogen.

The averages also hide the fact that for those operations with any assimilative nitrogen capacity, the ratio of recoverable manure nitrogen to assimilative capacity is 13. This means that for every unit of onfarm assimilative capacity, there are 13 units of manure nitrogen that are produced. Operations with little assimilative capacity produce similar quantities of recoverable manure nitrogen to operations with greater assimilative capacity, leading to the high ratio of manure nutrients produced to assimilative capacity.[12] This ratio increases by the size of an AFO; large AFOs have a ratio of 91 lb of manure nitrogen produced for each pound of onfarm nitrogen assimilative capacity.

Table 6

Estimated nitrogen and phosphorus generation and uptake, Chesapeake Bay operations, 2012

Type of Farm	Percent of nitrogen assimilative capacity in region	Percent of recoverable manure nitrogen produced in region	Percent of phosphorus assimilative capacity in region	Percent of recoverable manure phosphorus produced in region
All	**100**	**100**	**100**	**100**
No livestock -- Less than 100 acres of cropland	4	0	4	0
No livestock -- 100 or more acres of cropland	32	0	30	0
Some livestock but not likely to be confined	23	0	27	0
All animal feeding operations (AFOs)	42	100	39	100
Small AFOs	26	31	24	30
Medium AFOs	10	39	9	40
Large AFOs	6	30	5	30

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

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

---

[12] The bottom third of AFOs with any assimilative capacity includes those with between 1 and 4,212 pounds of nitrogen capacity. These operations generate, on average, 16,410 pounds of recoverable manure nitrogen. The top third have more than 9,648 pounds of assimilative capacity, but generate 13,628 pounds of recoverable manure nitrogen.

Table 7

Estimated nitrogen and phosphorus generation and uptake, Chesapeake Bay animal feeding operations, 2012

Nitrogen					
Type of farm	Average assimilative capacity of nitrogen (lb)	Average recoverable nitrogen produced (lb)	Percentage with any nitrogen assimilative capacity	Average ratio: recoverable nitrogen/assimilative capacity of nitrogen[1]	Percent of farms with excess nitrogen
All AFOs	**44,913**	**15,182**	**90**	**13**	**26**
Small AFOs	35,860	5,874	94	3	15
Medium AFOs	62,140	34,947	76	49	63
Large AFOs	149,060	113,623	74	91	69

Phosphorus					
Type of farm	Average assimilative capacity of phosphorus (lb)	Average recoverable phosphorus produced (lb)	Percentage with any phosphorus assimilative capacity	Average ratio: recoverable phosphorus/assimilative capacity of phosphorus[2]	Percent of farms with excess phosphorus
All AFOs	**5,133**	**6,851**	**90**	**20**	**46**
Small AFOs	4,085	2,580	94	6	37
Medium AFOs	7,118	16,204	76	76	81
Large AFOs	17,229	50,816	74	125	87

AFOs = animal feed operations.

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

[1] Just farms with non-zero nitrogen assimilative capacity. [2] Just farms with non-zero phosphorus assimilative capacity.

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

The situation is even more pronounced when examining phosphorus. The average amount of phosphorus generated via manure is greater than the average assimilative capacity at AFOs. This leads to 46 percent of AFOs generating excess phosphorus, and a ratio of 20 lb of manure phosphorus produced for every pound of assimilative capacity. Again, these numbers increase with size of AFO; 87 percent of large AFOs generate excess manure phosphorus. For large AFOs with any phosphorus assimilative capacity, there are 125 lb of recoverable manure phosphorus for each unit of assimilative capacity.

Examining just the AFOs with onfarm excess manure nutrients reveals the extent to which these operations generate more nutrients than they can use onsite (table 8). A major reason for onfarm excess manure nutrients is that 39 percent of the operations with excess nitrogen and 21 percent of the operations with excess phosphorus have no assimilative capacity for these nutrients.[13] Hence, for these operations, a solution to mitigate excess would not be better land nutrient management. For those with assimilative capacity and excess nutrients, the amount generated far exceeds the assimilative capacity, with a ratio of 73 units of manure nitrogen and 48 units of manure phosphorus for every unit of assimilative capacity. The total amounts of excess manure nutrients are concentrated at medium and large AFOs. While constituting only 3 percent of agricultural operations in the Bay area, medium and large AFOs generate 90 percent of onfarm excess manure nitrogen and 87 percent of onfarm excess manure phosphorus.

---

[13] Note that “excess” is defined by comparing the amount of recoverable manure nutrients onfarm to the amount of assimilative capacity onfarm. Fertilizer nutrients may also be applied, yielding even larger excesses.

Table 8

Estimated nitrogen and phosphorus generation and uptake, Chesapeake Bay AFOs with excess N or P, 2012

Operations with onfarm excess nitrogen

Type of farm	Percentage with any nitrogen assimilative capacity	Average assimilative capacity of nitrogen (lb)	Average recoverable nitrogen (lb)	Average excess nitrogen, by farm (lb)	Average ratio: recoverable nitrogen/ assimilative capacity of nitrogen[1]	Percent of onfarm excess nitrogen
All AFOs	**61**	**5,217**	**32,468**	**27,250**	**72**	**100**
Small AFOs	60	1,655	7,756	6,101	33	10
Medium AFOs	62	6,097	37,049	30,952	94	48
Large AFOs	63	17,126	120,968	103,842	156	42

Operations with onfarm excess phosphorus

Type of farm	Percentage with any phosphorus assimilative capacity	Average assimilative capacity of phosphorus (lb)	Average recoverable phosphorus (lb)	Average excess phosphorus, by farm (lb)	Average ratio: recoverable phosphorus/ assimilative capacity of phosphorus[2]	Percent of onfarm excess phosphorus
All AFOs	**79**	**1,949**	**10,838**	**8,889**	**48**	**100**
Small AFOs	84	1,177	3,087	1,909	16	13
Medium AFOs	70	2,408	16,849	14,441	101	48
Large AFOs	70	6,544	51,503	44,959	152	38

AFOs = animal feed operations.

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

[1] Just farms with non-zero N assimilative capacity. [2] Just farms with non-zero P assimilative capacity.

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

Animal feeding operations appear to contribute a disproportionately large share of Bay pollution

These estimates of manure acreage, manure nutrient production, and assimilative capacity suggest that AFOs contribute a disproportionate and large share of agricultural nutrient pollution to the Chesapeake Bay watershed. As mentioned above, the EPA estimates that land-applied manure contributes nearly 40 percent of agricultural nitrogen loadings and three-quarters of agricultural phosphorus loadings to the Chesapeake Bay. AFOs control 63 percent of manure-applied acres but only constitute 15 percent of farms, suggesting that targeting improvements in nutrient management practices on these operations may be efficient. Despite their generation of manure nutrients, only 60 percent of AFOs apply manure to fields, and those that do so apply manure to only 59 percent of crop and pasture acreage. This suggests that efforts to improve the extent of land application of manure might be cost-effective.

While small AFOs cover a large percentage of manure acreage (41 percent) as well as manure nutrients produced (approximately one-third), they are less likely than medium and large AFOs to produce onfarm excess manure nutrients. Medium and large AFOs constitute only 3 percent of Chesapeake Bay farms, but produce 90 percent of onfarm excess nitrogen and 86 percent of onfarm excess phosphorus. Approximately two-thirds of medium and large AFOs have excess onfarm manure nitrogen, while over three-quarters of medium and large AFOs have excess onfarm manure phosphorus. Further, these types of operations control just 22 percent of manure acreage, suggesting they have more pronounced over-application issues than small AFOs.

While these estimates provide indications of the relative contribution by AFOs, they do not include factors related to runoff control. If, for example, AFOs are more likely to institute nutrient management than crop-only producers, this may counteract their disproportionate manure acreage and production. However, given prior research suggesting that manure appliers are less likely to institute nutrient controls (Ribaudo et al., 2011), and given that AFOs are more likely to apply manure, this seems unlikely.

Policies Aimed at Limiting Nutrient Discharges From Livestock Operations

Federal Clean Water Act concentrated animal feeding operation rules

While both crop and livestock operations potentially pollute water, the Clean Water Act (CWA) only regulates CAFOs. Originally instituted in 1972, the CWA CAFO regulations have been updated numerous times, most recently in 2011 (77 *Federal Register* 44494-44497 and U.S. EPA, 2013). The CWA sets a minimum level of regulation; enforcement is devolved to the States, which can adopt their own, more stringent rules. Nutrient trading programs generally require participants to satisfy all regulations before selling credits; hence, understanding the CWA CAFO rules is pertinent for comprehending how livestock operations may engage in Chesapeake Bay nutrient trading.

Under the Federal regulations, farms with livestock are first characterized by whether or not they are "animal feeding operations" (AFOs). To be classified as AFOs, operations must have animals confined for 45 days or more in any single year and not grow vegetation in the area of the facility where animals are raised and manure is stored (called the "production area").[14] Once classified as an AFO, a livestock 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 (table 9), and permit requirements vary by size.

Table 9

Size thresholds for Clean Water Act CAFO regulations

	Small	Medium	Large
Cattle (other than mature dairy cows)[1]	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

AFO = Animal feeding operations. CAFO = Concentrated animal feeding operations.

Note: Not all AFOs are CAFOs. AFOs that are "large" are automatically "large CAFOs," regardless of whether a discharge at the facility has been documented. Medium-sized AFOs are defined to be "medium CAFOs" if they discharge via a man-made 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, based on discharges and other factors.

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

Source: U.S. Environmental Protection Agency, 2003.

---

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

AFOs that are “large” are automatically “large CAFOs,” regardless of whether a discharge at the facility has been documented. 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, based on discharges and other factors. 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 and are regulated as point sources.

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 Federal Register 44494-44497; Centner and Newton, 2011). Because small and medium AFOs are designated as CAFOs when there is a documented discharge, they need to obtain permits. Large CAFOs, on the other hand, do not need to obtain permits unless there is a documented discharge.

The CAFO permit divides the livestock facility into two parts, pertinent for classifying discharges as “point” or “nonpoint.” 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.[15] 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.[16]

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 the production area, and such effluent is considered a “point source” discharge. Since the permitted facility can discharge from the production area only in unlikely conditions, the CAFO permit is characterized as “no discharge.” A 2012 rule amendment stipulated 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.

With regard to the land application area, the CAFO permit requires the implementation of a nutrient management plan (NMP) that follows specific guidelines, including minimizing nutrient runoff, sampling of manure and soil, periodic inspection of land application equipment, and setback distances (U.S. 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 and is following the NMP, it is allowed to have runoff from the land application area due to normal precipitation. These land application area discharges are considered “nonpoint source” and are excluded from permit oversight based on an exemption barring regulation of agricultural stormwater.[17]

---

[15] The land area around the production area not used for manure application is not directly referenced in the Federal CAFO permit, but it is a feature of Chesapeake Bay nutrient loading calculations (for details, see Water Quality Goal Implementation Team, 2011). This area is considered a potential source of nonpoint source pollution in Chesapeake Bay models of nutrient loadings.

[16] At most, the Federal CAFO NPDES permit requires livestock producers who transfer manure to other persons to keep records of the amount transferred and to provide nutrient content of the manure to the recipient (U.S. EPA, 2002).

[17] In tallies of nutrient loadings to the Chesapeake Bay by source, these nonpoint-source land-application discharges are not attributed to CAFOs; instead, they are included in the “agricultural nonpoint source” category along with runoff from non-CAFO facilities.

No empirical research has examined the effect that the regulations have had on environmental outcomes after adoption. At best, before adopting the updated regulations in 2003, the EPA performed analysis suggesting what effect the CAFO regulations would have on water quality (Code of Federal Regulations, 2003; p. 7176-7274). The environmental impact analysis suggested that the more stringent land-application rules would reduce nutrient loadings from affected large and medium CAFOs by 22 percent. Environmental groups have criticized the regulations as not being stringent enough to protect water quality (Copeland, 2006). A 2008 Government Accountability Office report criticized the EPA for not collecting data on regulated CAFOs, and suggesting that "EPA does not have the information it needs to effectively regulate these operations" (U.S. GAO, 2008, p. 5).

State and regional regulations and programs

The EPA devolves enforcement of the Federal regulations to individual States. States can also adopt their own regulations as long as they are at least as stringent as Federal ones, and may institute size thresholds different from the Federal ones. Table 10 compares stipulations of the Federal regulations for large CAFOs with those of the States in the Chesapeake Bay watershed. While there are some differences across States, the regulations are largely similar for large CAFOs. In addition to regulations for large-scale operations that often involve individual permits, many of the Bay States have also instituted stipulations for smaller scale AFOs. Three Bay States—Maryland, Delaware, and Virginia—have adopted mandatory nutrient management plans for all AFOs (Perez, 2011).

Despite the Federal CAFO rules being adopted, enforcement has been questioned in many States (Center, 2004); as such, the EPA occasionally sues individual States for not enforcing their CAFO regulations (U.S. GAO, 2003). The lack of enforcement may explain why a review of nutrient management practices in the Chesapeake Bay watershed found that full nutrient management does not occur on the majority of acreage, particularly that to which manure is applied. USDA's Natural Resources Conservation Service (NRCS) found that between 2003 and 2006, appropriate nitrogen application rates, application method, and timing of application occurred on only 13 percent of cropped acres (USDA-NRCS, 2011). Only 1 percent of cropped acres with manure applied met a high level of nutrient management criteria. A later report found that between 2003-2006 and 2011, manure was used as a nutrient source on more acres and applied at higher rates per acre. The percentage of cropped acres with manure applied that met a high level of nutrient management criteria remained low (USDA-NRCS, 2013). Based on the TMDL adoption and continuing encouragement of nutrient management measures, these practices may have become more prevalent.

Table 10

Federal and State permit requirements of confined animal feeding operations (CAFOs) in the Chesapeake Bay

Federal	Permit requirements for large CAFOs
	• 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 Nutrient Management Plan (NMP) • Implement manure and soil testing • Prevent direct contact of confined animals with waters of the United States • Recordkeeping • One of the following: Implement 100-foot setback for manure application from waters of the United States Implement a 35-foot vegetative buffer
State	Permit requirements for large CAFOs
Delaware	• All Federal stipulations • Nutrient management plan • Implement NMP according to phosphorus standard
Maryland	• All Federal stipulations • Soil and water quality conservation plan • Alternatives to 100-foot setback or 35-foot vegetative buffer • Implement NMP according to phosphorus standard
New York	• All Federal stipulations • Comprehensive NMP to Natural Resources Conservation Service standards
Pennsylvania	• All Federal stipulations • Erosion and sediment control plan for acreage that is plowed or tilled • Implement NMP according to phosphorus standard
Virginia	• All Federal stipulations • Compliance with local zoning ordinances • Implement NMP according to phosphorus standard • Groundwater monitoring • Implement setback of 200 feet from occupied dwellings not on owner's property • Implement 100-foot buffer zone from water supply wells or springs
West Virginia	• All Federal stipulations

Source: Federal permit information–U.S. Environmental Protection Agency, 2003; State CAFO permit information–Maryland Department of the Environment, 2009, 2010b; Commonwealth of Pennsylvania, 2006; Virginia Administrative Code 9VAC 25-192-70; National Association of State Departments of Agriculture, 2000; West Virginia Department of Environmental Protection, 2010.

Voluntary financial assistance programs for discharge reductions

In addition to regulatory measures to discourage nutrient pollution, a number of USDA, State, regional, and local programs aim to encourage practices to reduce agricultural nonpoint-source pollution. A suite of USDA programs offers financial assistance to farmers to implement practices that reduce nutrient runoff, including USDA's Chesapeake Bay Watershed Initiative, Conservation Reserve Program (CRP), Conservation Reserve Enhancement Program (CREP), and Environmental Quality Incentives Program (EQIP).[18]

EQIP is run by USDA-NRCS, offering financial and technical assistance to farmers to address a host of environmental concerns. EQIP is of particular interest for this study because it is the largest of the

---

[18] For more information on the USDA conservation programs, see http://www.usda.gov/wps/portal/usda/usdahome?navid=conservation.

working-lands conservation programs, and it is also the only one that specifically targets support to livestock producers to relieve the burden associated with environmental regulations; at the national level, 60 percent of EQIP funding is designated for livestock producers.

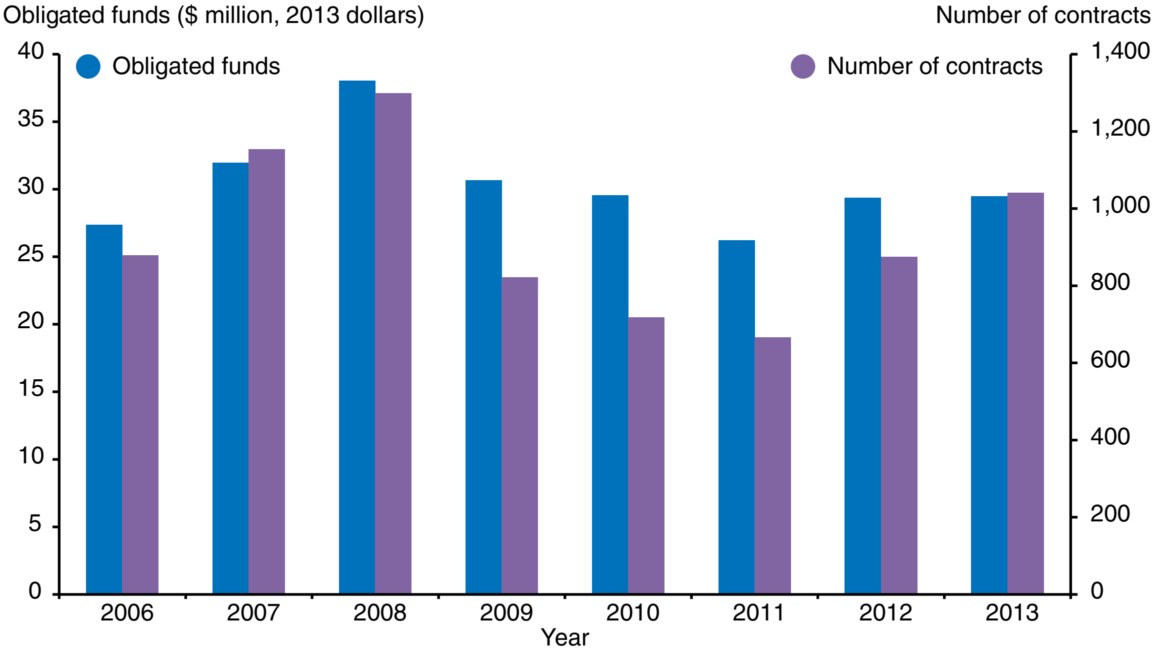
Figure 13 shows the obligated funds provided by NRCS and the number of EQIP contracts awarded to livestock producers in Chesapeake Bay counties between 2006 and 2013.[19] In this time period, NRCS funded a total of 7,452 contracts, an average of 932 per year. This amounted to nearly $243 million, or $30 million per year (in 2013 dollars). Note that there were over 70,000 operations with livestock in the Chesapeake Bay counties in 2012, so only a small percentage (about 1 percent) would have received EQIP funding in a year.[20]

Each EQIP contract may include multiple practices, and hundreds of specific practices are funded. Figure 14 shows EQIP funding to livestock operations in Chesapeake Bay counties between 2006 and 2013 by the most prevalent practices. The largest percentage of spending was for waste-storage facilities followed by protection for heavy-use areas. Protection of heavy-use areas generally refers to stabilizing land in order to reduce sedimentation and nutrient runoff. Fencing to restrict animals from waterways or other areas receives the third highest amount of funds.

While the prior figure shows which types of practices receive the most funding, certain practices are much less costly but more prevalent. Figure 15 shows the percentage of practices funded for the same period and population. While a relatively small proportion of contract items are for waste

Figure 13

Obligated funds and number of EQIP contracts at operations with livestock, Chesapeake Bay watershed counties, 2006-2013



EQIP = USDA, Environmental Quality Incentives Program.
Source: USDA, Economic Research Service calculations based on USDA, Environmental Quality Incentives Program data.

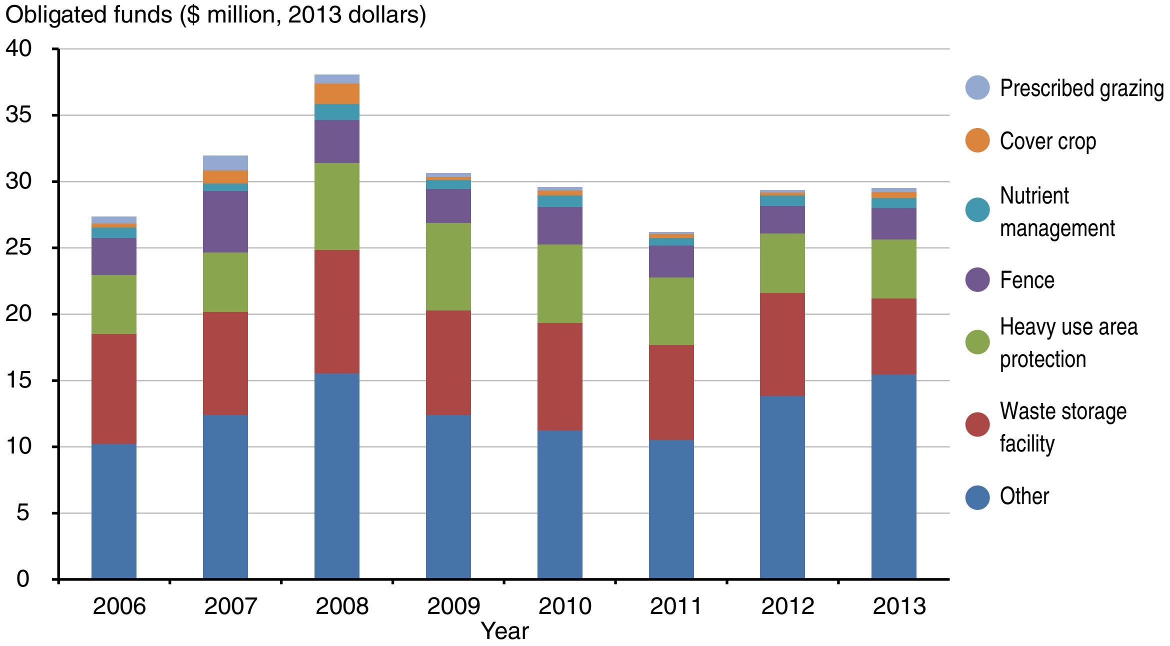
---

[19] Funding is for the year in which it was granted (obligated), not necessarily the year it was spent.

[20] Some producers are not eligible for EQIP financial assistance based on past assistance received and limits on operator income. However, even assuming that all of the EQIP contracts went to the approximately 15,000 AFOs in the Chesapeake Bay, only 6 percent of AFOs are enrolling in EQIP in each year.

Figure 14

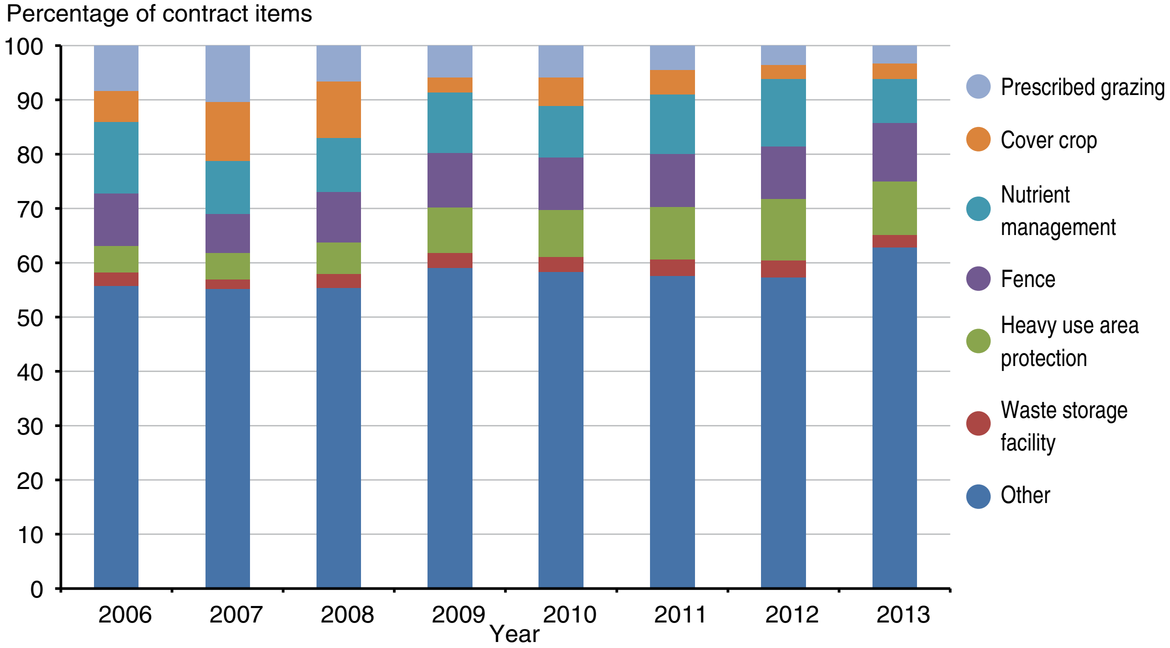
Obligated funds by specific EQIP practice, operations with livestock in Chesapeake Bay watershed counties, 2006-2013



EQIP = USDA, Environmental Quality Incentives Program.
Source: USDA, Economic Research Service calculations based on USDA, Environmental Quality Incentives Program data.

Figure 15

Percentage of EQIP contract items by specific practice at operations with livestock, Chesapeake Bay watershed counties, 2006-2013



EQIP = USDA, Environmental Quality Incentives Program.
Source: USDA, Economic Research Service calculations based on USDA, Environmental Quality Incentives Program data.

storage or heavy-use protection, more are devoted to nutrient management and cover crops. In an individual year, 11 percent of contracts included funding for nutrient management plans, 9 percent included funding for fencing, and 6 percent included funding for cover crops.

Total maximum daily load (TMDL) requirements

Despite Federal and State regulation as well as voluntary and subsidized efforts, Chesapeake Bay water quality still does not meet Government water quality goals. When this happens, the EPA can require States to enact a "total maximum daily load" (TMDL) for the area. A TMDL defines the maximum amount of pollutants that can enter the water body while still meeting water quality goals. The TMDL is achieved via a plan often described as a "pollution diet." Despite decades of restoration attempts, the Bay continues to have poor water quality. Hence, in 2010, the EPA adopted the Chesapeake Bay TMDL.

To implement the TMDL, States within the watershed must adopt watershed implementation plans (WIPs) that outline practices to be instituted to reduce pollution. Every 2 years, milestones are assessed in the WIPs. Additional tracking enables the EPA to establish whether progress is being made in an appropriate timeframe. The EPA estimates that all practices and steps necessary to meet the Bay's water-quality goals will be in place by 2025 (U.S. EPA, 2010).

The WIPs establish practices pertinent to individual States to reduce nutrient runoff. A focus in all WIPs is the management of animal wastes (Maryland Department of the Environment, 2010a; Commonwealth of Virginia, 2010; Pennsylvania Department of Environmental Protection, 2010; Delaware Chesapeake Interagency Workgroup, 2010; New York State Department of Environmental Conservation, 2010; West Virginia WIP Development Team, 2010). These include requirements to inject wastes into soil, install nutrient management plans, implement greater oversight of CAFO regulations, and enact other best management practices (BMP) to dispose of manure. While 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, there are no additional stipulations for CAFOs under the Chesapeake Bay TMDL.

The WIPs largely redouble efforts devoted to the traditional policy approaches outlined above. Based on the past failure of these approaches to garner the nutrient reductions required, many have called for innovative policy approaches, given the observed funding levels. One newer policy type included in the Chesapeake Bay TMDL is establishment of baywide nutrient trading. The next section describes the EPA's proposed program for nutrient trading in the Bay, as well as how livestock operations could participate in it.

Nutrient Trading in the Chesapeake Bay

Nutrient trading is a market-based mechanism designed to reduce nitrogen- and phosphorus-based water pollution at potentially lower costs than otherwise would occur with traditional methods, namely technology standards (or "command and control" policies). Aside from theoretically being more efficient at pollution reduction, nutrient trading programs are seen as more flexible because they allow polluters a number of options to satisfy their contributions to overall pollution reduction. They can also incentivize unregulated nonpoint sources to lower their discharges.

Nutrient trading operates similarly to cap-and-trade programs for air pollutants, in which regulated entities must obtain permits to emit pollution. An operating example of an air-pollution trading market was the Acid Rain Program, established in 1990 by the EPA to reduce emissions of sulfur dioxide and nitrogen oxides from the power sector. The program capped the amount of sulfur dioxide that could be emitted by U.S. power plants, with the final 2010 cap set at half the 1980 emissions level (U.S. EPA, 2015). To meet its effluent reduction target, a regulated firm could reduce its own pollution or purchase credits from another "capped" firm, which in turn would be required to reduce emissions. Alternatively, a regulated firm could meet its target by paying a non-regulated emitter to reduce emissions (U.S. EPA, 2014b).

The prior literature on nutrient trading has pointed out its theoretical and practical problems, including those related to agricultural operations' participation. While the success of pollution trading has occurred through air-pollution trading markets, water quality trading's track record is much less positive (King and Kuch, 2003; King 2005; Morgan and Wolverton, 2008). As described in much prior research (Breetz et al., 2010; Ribaudo et al., 2011; King and Kuch, 2003; King, 2005; Ribaudo and Gottlieb, 2011; Morgan and Wolverton, 2008; Newburn and Woodward, 2011; Abdalla et al., 2007), concerns arise over the following issues (many of these concerns can be addressed through careful program design):

- The ability to measure the level of discharge reduction from practices employed at nonpoint sources. In order to monitor and enforce reductions, discharge reductions are assigned to practices; this enables regulators to oversee the practice, rather than the discharge reduction amount.
- Monitoring and enforcement of reductions. To adjust for the uncertainties associated with the levels of discharge reduction associated with the practices as well as other uncertainties, trading ratios are factored in, such that each unit of reduction only counts toward a partial credit.
- Generating pollution "hot spots" if point sources buying credits cluster geographically. To address generation of "hot spots," trades can be limited to geographic boundaries or trading ratios can be adjusted to account for regional nutrient loads.
- Adequate supply and demand for credits. To address a lack of demand for credits, restrictions on regulated point sources or TMDL caps can be made more stringent.
- Contract enforcement of trades.
- Transaction costs involved with finding credit buyers, negotiating trades, and verifying practices.

Notably, for purposes of this report, these concerns generally do not differ between crop-only and livestock producers. However, there have been four areas of prior research in which details may differ between the two types of producers:

- Costs of meeting baseline requirements, and whether public financial assistance could be used for this purpose.
- Whether producers will increase pollution practices in one area of their operation while adopting pollution reduction practices in another.
- Additionality. The reduction in nutrient discharges need to be additional to those that would have occurred in the absence of trading. Guaranteeing additionality can be supported by program design.
- Farmers' willingness to participate in regulation-driven programs. To address farmers' distrust of regulatory agencies, partnerships can be made with agricultural groups, who can introduce nutrient trading to potential participants (Breetz et al., 2010).

While a baywide nutrient trading program has not been established, five States in the Bay watershed area have proposed some type of trading. Four States—Maryland, Virginia, Pennsylvania, and West Virginia—have introduced (but not necessarily implemented) trading programs, while Delaware has discussed such a program (Branosky et al., 2011; Chesapeake Bay Commission, 2012; Walker and Selman, 2014). However, few trades have taken place thus far.

Discharge limits for point and nonpoint sources under the Chesapeake Bay TMDL

The Chesapeake Bay TMDL establishes a limit on the amount of pollutants that can be discharged into the water body and its tributaries, and contributors to the limit are assigned allowable amounts of discharge. The allowable discharges can be assigned to individual entities (in the case of regulated point sources) or groups (in the case of nonpoint sources). Regulated point sources are assigned discharge limits via their individual permits; the TMDL generally requires permitted limits lower than pre-TMDL standards. Discharge limits for unregulated nonpoint sources, such as most agricultural sources, are generally assigned by group. The discharge reduction methods employed do not require every individual farm to impose reductions. Instead, the goal is to voluntarily induce discharge reduction from those operations with relatively more impact on water quality. The proposed Chesapeake Bay nutrient-trading program guidelines allow trading between individual point sources and between point and nonpoint sources. Both point and nonpoint sources can be sellers of credits, but only regulated point sources would be buyers.

Baseline requirements

Before a source can generate credits for sale, it must first meet baseline requirements. The baseline is defined as "the pollution control requirements that apply to a buyer and seller in the absence of trading" (U.S. EPA, 2009b, p. 6, in "Point source–Nonpoint source trading scenario"). Under the TMDL, permitted discharges for regulated point sources are lower than they were before the TMDL. This reduced amount establishes the "baseline" for regulated point sources. Reductions beyond the baseline can be used to generate sellable credits in nutrient trading programs.

The "baseline" has a different connotation for nonpoint sources hoping to participate in nutrient trading. Since they are unregulated, nonpoint sources are not required to lower their discharges under the TMDL. However, under EPA and Chesapeake Bay Program nutrient trading guidelines, to participate in trading, nonpoint sources must reach a baseline before generating credits. Further reductions (or additional practices) beyond the baseline must be instituted to generate credits. The baseline requirements for agricultural nonpoint sources that hope to participate in nutrient trading include a number of management practices; those for the trading programs established in Bay States are shown in table 11.

Baseline requirements for nonpoint sources have been found to be nontrivial in their effect on agriculture's willingness to participate in nutrient trading. Depending on their stringency, baseline requirements can make credit generation more expensive and therefore reduce the number of sellable credits (Ribaudo et al., 2014). What remains unexplored in the prior literature is how CAFO rules may factor into baseline requirements.

Table 11

Baseline requirements for agricultural nonpoint sources

State	Requirements
Maryland	• Achieve reduced per-acre nutrient loading rates according to Total Maximum Daily Load (TDML) specifications • Comply with all applicable regulations • Implement Nutrient Management Plan (NMP) • Implement soil and water conservation plan and waste management system plan
Pennsylvania	• 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	• 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	• Comply with all applicable regulations • Achieve Tributary Strategies per-acre loading rates • Implement whole-farm NMP

Note: 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.
Source: Baseline requirement information from Branosky et al., 2011, p. 9; and Latane and Stephenson, 2011.

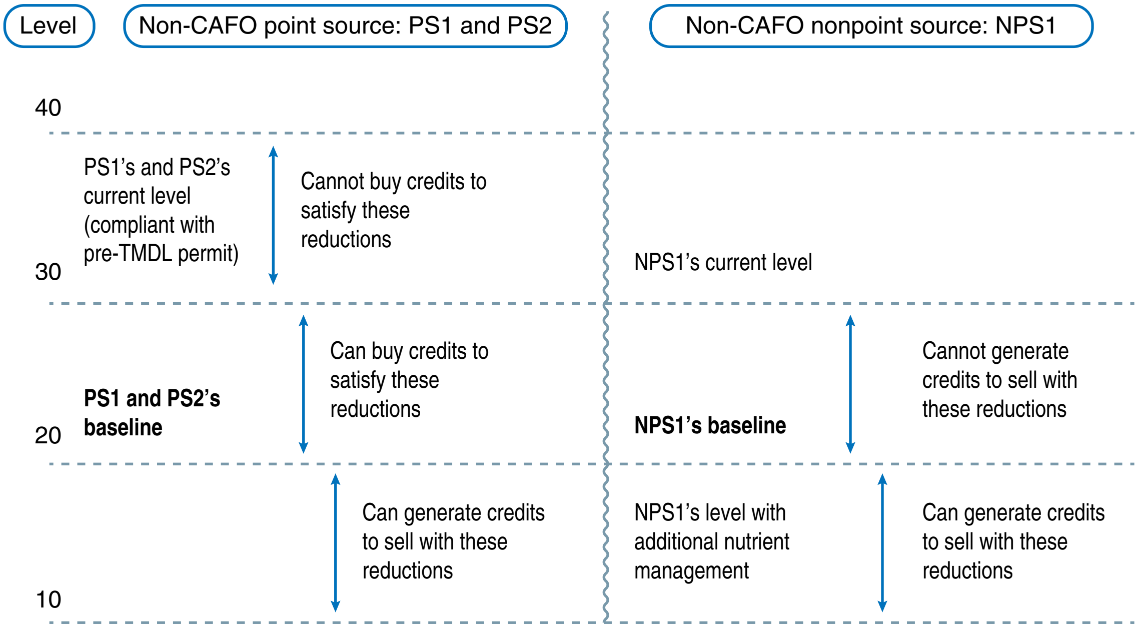
Trading between point sources

To illustrate how CAFOs and other livestock operations could participate in nutrient trading, it is first useful to demonstrate how point and nonpoint sources can generate and sell credits. Consider the discharge levels from a permitted non-CAFO point source in the Chesapeake Bay; call this PS1 (fig. 16). Prior to the TMDL, the permit for PS1 requires technology standards yielding a discharge level of 30. However, the TMDL adds further discharge reductions, which require PS1 to limit discharges to the baseline level of 20. In the absence of nutrient trading, suppose PS1 would have to pay $600 to install expensive discharge control technologies to reach a discharge level of 20.

Now consider a second non-CAFO point source in the Chesapeake Bay called PS2. Prior to the TMDL PS2 is also following its permit and discharging at level 30. Under the TMDL, PS2 also

Figure 16

Pollution load levels pertinent for nutrient trading by non-CAFO point and nonpoint sources



CAFO = confined animal feeding operation.
TMDL = total maximum daily load.
Note: Level describes discharge load. Numbers are for expository purposes. See text for further description.
Source: USDA, Economic Research Service.

faces the discharge limit of 20. However, PS2 can reduce its discharges to level 20 for an expense of only $200, and can reduce to 10 for an additional expense of $200. Thus, PS2 can reduce from 30 to 10 for a total expense of $400. Without trading, PS2 has no incentive to reduce its discharges to 10 for an expense of $400, only to 20 at an expense of $200. The total pollution from the two point sources would be 40, with a total abatement cost of $800.

If nutrient trading were allowed, the same level of pollution could be reached at a lower total cost. PS2 could reduce its discharges to level 10 at a cost of $400, and then sell 10 credits to PS1 for some cost greater than $200. PS1 would be willing to buy 10 credits for some expense lower than $600. Suppose PS1 and PS2 agree on a price of $300 for 10 credits. PS1 could then use these credits to achieve its baseline at 20, rather than institute the expensive reduction technologies. The overall discharge amount from these two point sources would still be 40 (the same as it would have been without nutrient trading). PS2 will have spent a net sum of $100 in reductions while PS1 will have spent $300. The overall cost of achieving this discharge level would be $400, which is less than what it would be without trading.

If PS1 is not compliant with its pre-TMDL effluent limit, and is discharging at level 40, Chesapeake Bay nutrient trading guidelines from the EPA state that PS1 could not buy credits to reach level 30 from level 40 (Chesapeake Bay Program, 2001; and U.S. EPA, 2009a).

Trading between point and nonpoint sources

Next consider a nonpoint source in the Chesapeake Bay, NPS1. NPS1 is not subject to CWA permitting requirements and is discharging at level 30 in figure 16 (note that the discharge levels are not meant to be indicative of actual levels or comparisons between point- and nonpoint-source polluters).

If NPS1 wants to generate nutrient credits to sell, the trading program requires it to first institute certain practices that place its discharges at a baseline level of 20. Suppose reduction from level 30 to level 20 costs $100. NPS1 can then institute additional nutrient management practices and reduce its discharges from level 20 to level 10 at a cost of $200. NPS1 can then sell 10 credits to PS1, and would be willing to do so at 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 in figure 16. PS1's cost (i.e., $400) would be lower than it would have had to pay without nutrient trading (i.e., $600). Further, NPS1 gains a profit of $100.

Livestock operations' participation in nutrient trading

The nonpoint source in figure 16 is representative of a crop-only farmer participating in nutrient trading. Livestock producers may participate differently due to baseline stipulations, which require satisfying all regulations and instituting certain practices. Individual State trading programs require NMPs and other nutrient-runoff controls pertinent to land-applied manure. There is overlap between the practices required to satisfy the baseline and those required for CAFO regulation, such that some livestock producers will have already at least partially satisfied baseline requirements before entering into nutrient trading.

Not only are there differences between livestock and crop-only producers in regulatory requirements and NMP adoption, but these differences are also present between types of livestock producers (table 12). Permitted CAFOs will satisfy regulatory requirements and have nutrient runoff controls, but their potential production of both point- and nonpoint-source discharges complicates nutrient trading participation. Unpermitted CAFOs with nutrient management plans and nutrient runoff controls have already satisfied certain baseline requirements, but may face inspection by trading authorities to guarantee that they are abiding by regulations.[21] This can pose a deterrent to participation if unpermitted CAFOs wish to avoid inspection but trading authorities require it to confirm regulatory compliance. Unregulated AFOs may not be required to have nutrient runoff controls but may also be hesitant to approach trading authorities based on inspection fears (Breetz et al., 2010). These features mean that livestock operations face different costs to meeting baseline requirements and participating in nutrient trading.

Table 12

Differences between agricultural producers in stipulations in place before nutrient trading participation

	Type of operation			
Stipulation	Permitted CAFO	Unpermitted CAFO with NMP and other nutrient runoff controls	Non-CAFO AFO	Crop-only producer with no livestock
NMP and other nutrient runoff controls	Yes	Yes	Varies by State	No
Inspection by regulatory body	Yes	No	No	No
Potentially needing an NPDES permit	Yes	Yes	Yes	No

CAFO = confined animal feeding operation. AFO = animal feeding operation. NMP = nutrient management plan.
NPDES = National Pollution Discharge Elimination System.
Source: USDA, Economic Research Service.

---

[21] Note: If an unpermitted CAFO has instituted an NMP, the CAFO can have runoff from the land application area due to normal precipitation.

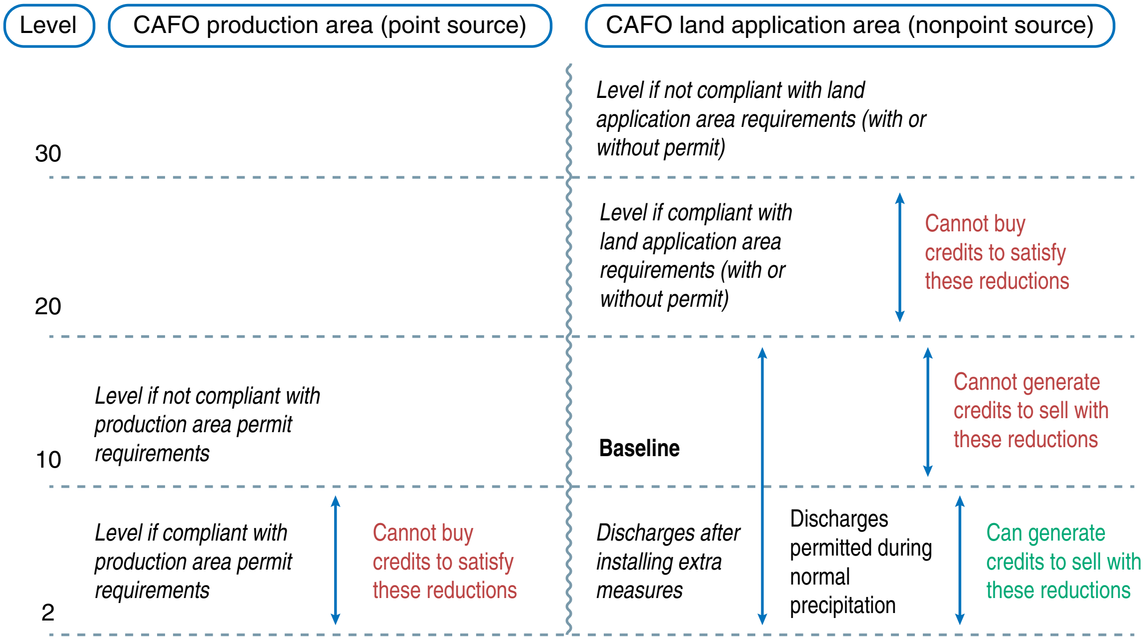
Confined animal feeding operations with permits

Permitted CAFOs create certain legal discharges from both production and land application areas, although one of these discharges is considered from a point source and one is from a nonpoint source. To understand how permitted CAFOs may and may not engage in nutrient trading, it is helpful to consider these two areas separately. Figure 17 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. Despite the fact that CAFO permits are called "no discharge" or "zero discharge," they do allow for discharges related to major storm events. Under "normal" circumstances, the CAFO would only have discharges from its production area related to rare storm events (a discharge level of 2 in Figure 17). Since there are no additional discharge reduction requirements for permitted CAFOs under the Chesapeake Bay TMDL, this operation does not have to reduce its point-source effluent further.

Now consider the nonpoint-source discharge levels pertinent to the land application area of the permitted CAFO (right-hand side of figure 17). The CAFO is operating in compliance with its land application permit requirements and generates nonpoint-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 (at level 10) to level 2. Theoretically, the permitted CAFO could then sell eight 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 2, then the permitted CAFO would have an economic incentive to participate in nutrient trading by selling credits generated from its land application area.

Figure 17

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



CAFO = confined animal feeding operation.
Note: Level describes discharge load. Numbers are for expository purposes. See text for further description.
Source: USDA, Economic Research Service.

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 would be very difficult to reduce discharges related to unpredictable rare storm events. Because the CAFO permit has no 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 the CAFO 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 those additional program-specific measures to reach the baseline and participate in nutrient trading.

Confined animal-feeding operations without permits and unregulated animal-feeding operations

As described in a previous section, even if an operation is defined as a CAFO, it does not need to obtain a permit if it does not have a documented discharge. If an unpermitted CAFO has an NMP and other nutrient runoff controls, then discharges from the land application area during regular precipitation are exempt from regulation. The difference between an unpermitted CAFO with an NMP and other runoff controls and a permitted CAFO is that the unpermitted CAFO's production area has not been inspected by the pertinent regulatory authority and the unpermitted CAFO has not had a documented discharge. 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 17, if the unpermitted CAFO (with appropriate runoff controls) was discharging at level 20 from its land application area and reduced to level 2, it could sell 8 credits.

If the unpermitted CAFO would like to sell these credits, it must approach the trading authority. The nutrient trading program authority may hypothetically examine the production area of the CAFO to make sure it is in compliance with applicable laws. Suppose this unpermitted CAFO were found to be discharging from its production area at level 10 (left-hand side of figure 17). 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 (U.S. EPA 2009a); to comply with its permit, the CAFO discharging from its production area at level 10 could *not* buy 8 credits to reach level 2 from level 10. If the unpermitted CAFO approaches the nutrient trading authority and says that it has a production-area discharge above level 2 that it would like to reduce and therefore sell as credits, the unpermitted CAFO could be fined for having unpermitted discharges. Thus, 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.[22] Thus, if a CAFO were to reor-

---

[22] 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.

ganize 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 unregulated 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, an unregulated 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, an unregulated AFO could theoretically participate in a nutrient trading program in a manner similar to crop-only producers (as in figure 16).

Other potential effects of confined animal feeding operations' rules on nutrient trading

The above descriptions illuminate how the CWA CAFO rules theoretically complicate livestock operations' participation in Chesapeake Bay nutrient trading. While such participation is already convoluted in theory, in practice, portions of it may be even more complex. In order to sell discharge-reduction credits, the nutrient trading authority must have some understanding of the amount of pollution from each type of discharge. While pollution reductions have been estimated for many types of practices, there are situations where such estimates have not been made. Quantifying these discharges and the amount reduced through various practices may be so difficult as to render impossible the generation by CAFOs of certain types of nutrient credits.

Barring these quantification and verification issues, if unpermitted operations that confine livestock face additional scrutiny with regard to the CAFO rules, they may elect to not participate in nutrient trading. If required to obtain a permit, a livestock operation may incur costs such as adjustments to the manure storage facility, permitting fees, and possible fines. 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 about obtaining permits (NRDC, 1998; Lyons, 2014; Copeland, 2011) and a number of livestock lobby groups have sued the EPA over prior Federal requirements to obtain permits (Kobell, 2013; NPPC, 2011), the costs of regulatory scrutiny may be pronounced.

These costs may yield differential benefits from nutrient trading between individual agricultural producers, based on State-level differences in regulations for livestock operations and practices necessary to establish baselines for nutrient trading. Differing State rules may mean that livestock and non-livestock producers vary in their ability to generate credits from the same behaviors. For example, setbacks are a permit requirement for large CAFOs (thereby not generating credits) but may qualify as a credit-generating practice for crop-only producers (depending on the State nutrient trading program requirements). Alternatively, one State may require large CAFOs to install certain nutrient management practices beyond federally mandated ones while another may consider these practices to generate credits.

Permitting expenses may mean that already-permitted facilities face fewer start-up costs to nutrient trading than unpermitted facilities. Thus, permitted facilities may be able to engage in nutrient trading more quickly and take advantage of any potential gains to early entry. Those who can document nutrient reduction practices sooner may shut out those still jumping regulatory hurdles, particularly if the demand for credits in a specific area is limited. Further, permitted facilities may offer more certainty with respect to credit generation ability, making credit buyers more likely to trade with them. Such differences may also occur between States. States requiring all AFOs to obtain permits (not just the ones that discharge) or with strong programs of documenting discharges would conceivably have more operations entering nutrient trading programs, relative to States with less stringent laws, or moving to areas with less regulation.

The complications involved with livestock operations participating in Chesapeake Bay nutrient trading may increase the price of credits, affecting the costs to non-agricultural point-source polluters of meeting discharge reductions. The higher cost of participation by livestock producers in a nutrient trading program could reduce the potential supply of credits, which could increase their price.

One indication of how much these complications could affect the potential supply of credits from agriculture is to examine the percentage of cropland and pastureland operated by livestock facilities in the Chesapeake Bay watershed, as many credit-generating methods involve land management practices (VA DEQ, undated). As shown in table 4, some 67 percent of farms in the Chesapeake Bay watershed counties have at least some livestock, and these operations operate 69 percent of cropland and pastureland. If livestock operations (regardless of size) avoid nutrient trading programs for fear of regulatory scrutiny, this could have a sizable impact on the supply of credits generated from agriculture.

Not all livestock operations may be similarly concerned about regulatory scrutiny. Large facilities may perceive higher costs to obtaining permits or subjecting themselves to regulatory oversight. Additionally, costs associated with getting permits may be greater for large operations depending on the cost to upgrade manure management methods. If large livestock operations do not participate in nutrient trading, this may have little impact on potential supply of credits. Again turning to table 4, operations with enough livestock to qualify as large CAFOs constitute about 1 percent of agricultural operations and operate only 3 percent of cropland and pastureland. Thus, if these types of operations did not want to engage in nutrient trading programs for fear of CAFO rules, then a large amount of nutrient credits generated from land management would likely still be available from operations with fewer or no livestock.

Finally, credit price could also be impacted if livestock producers could supply lower cost credits than non-livestock producers. This may be the case if the per-unit reductions in nutrient loadings resulting from manure management were less costly than those related to fertilizer management. If the livestock producer were deterred from nutrient trading due to concerns of regulatory oversight, this source of cheaper credits would be lost.

Modeling Farm-Level Participation in Nutrient Trading To Highlight Differences Between Crop and Livestock Producers

The prior section described how CAFO regulations can theoretically impact costs to meeting nutrient trading baseline requirements and impacting program participation. To comprehend the extent of these effects as well as other influences impacting livestock operations' participation in nutrient trading compared to crop producers, we develop a model incorporating the benefits and costs of nutrient credit generation. We parameterize this model and apply it to 2012 Census of Agriculture data.[23]

Model and assumptions

To examine potential differences between fertilizer and manure appliers in generating nutrient credits, we model a method of generating credits involving reductions to crop-applied nutrients. We model a scenario that requires producers to reduce nutrient application on all crops at the operation by 15 percent beyond the amount allowed in a nutrient management plan.[24] While there are other methods of participating in nutrient trading, in order to compare crop and livestock we focus on this one method, as both types of farms will be able to engage in this manner. However, this is generalizable to many methods of nutrient credit generation involving reduction of nutrient applications to land.

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. This assumption comes from the fact that in four States with operating or proposed nutrient trading (Maryland, Virginia, Pennsylvania, and West Virginia), the credit life is 1 year for nonpermanent credits (Branosky et al., 2011). In part, this addresses concerns with the risk inherent in future prices and multi-year contracts, which we do not explicitly model. All costs and benefits to participate are annualized.

The farmer will enter nutrient trading if the value of credits for sale is positive. The value of credits to the producer is the difference between the amount earned from the sale of the credits and the costs of meeting the baseline and generating the credits:

---

[23] A previous simulation using this model and applied to 2007 Census of Agriculture data appears in Sneeringer (2013). Several modifications have been made to the parameters and assumptions of the model for this report, complicating comparison between the two. In this report, generation of credits can only occur through reductions in nutrient applications to crops; Sneeringer (2013) allowed reductions to both cropland and pastureland. This report uses manure shipping distance estimates from Ribaudo et al. (2014) that vary by 6-digit hydrologic unit code (HUC6), whereas Sneeringer (2013) used constant manure-shipping distances regardless of location within the Chesapeake Bay. This report also assumes 40 percent transaction costs, unlike Sneeringer (2013). Prices for crops, per-unit manure shipping, and fertilizer have been updated to 2012 dollars. Sneeringer (2013) did not separately analyze AFOs with and without excess onfarm manure nutrients, while this report does.

[24] This is a 15-percent reduction of the amount of nutrients applied to each crop, not a 15-percent reduction in the overall use of nutrients (which could conceivably be achieved by completely eliminating all nutrient applications on a few acres). The reduction also does not pertain to pastureland.

(1) *Value of credits = Revenue from credit sales – Costs of meeting baseline*
– Costs of generating credits

The gross revenue from credit sales depends on the number of credits generated and the price of the credit:

(2) *Revenues from credit sales = Price per credit* × *Number of credits generated*

The number of credits generated through a 15-percent reduction in nutrients to cropland will depend on the amount of nutrient applications that are reduced and the trading ratio. Under this hypothetical program, farms are required to reduce 15 percent of the total amount of nutrients applied on crops (after meeting baseline requirements). Thus, the number of credits generated will depend on the number of nutrients applied to crop acreage. The number of credits generated will also depend on the trading ratio. Because nonpoint-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. A trading ratio greater than 1:1 means that for each unit of nutrients reduced, less than 1 credit will be generated. For example, a trading ratio of 2:1 means that a credit is generated for every two units of expected nutrient reduction, and a trading ratio factor would be 0.5. To calculate the total number of possible credits generated through a 15-percent reduction in nutrients applied to cropland:

(3) *Number of credits generated = 0.15* × *Pounds of nutrient applied to cropland*
× *Trading ratio factor*

Before the producer can enter nutrient trading, the operator must meet the baseline requirements, including a nutrient management plan (NMP) and other practices. The costs of meeting the baseline are the sum of these:

(4) *Costs of meeting baseline = Costs of implementing an NMP + Costs of other practices*

The costs of implementing the nutrient management plan (NMP) consists of a per-acre cost of developing a plan plus the cost of shipping manure off-farm if the farm has more nutrients than can be used onfarm. 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 fields' assimilative 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). Since State-level nutrient trading programs in the Bay watershed allow producers to use financial assistance to meet baseline requirements (but not to generate credits), the costs of developing the NMP will also depend on the financial assistance rate:

(5) *Costs of implementing a NMP = (Financial assistance rate* × *Cost of developing NMP)*
+ Cost of shipping manure

Here, the financial assistance rate is the proportion of costs borne by the farmer. If the farm is assumed to already have a NMP, then these costs are assumed to be zero for purposes of nutrient trading; the producer is also assumed to already be shipping all excess manure off-farm, so this is not assumed to be a cost related to entry in nutrient trading. Since the cost was born for a reason other than nutrient trading participation for these farms, it is not included in the costs of nutrient trading. We assume that AFOs in Virginia, Maryland, and Delaware already are following nutrient management plans because these States require NMPs for all AFOs (Perez, 2011). All other AFOs (of all sizes) must pay a per-acre NMP cost as well as the costs of shipping any excess manure off-farm (to meet the agronomic application rate of the NMP). A sensitivity analysis relaxes this assumption for large CAFOs.

The costs of meeting the other baseline practices will depend on the farms' acreage, whether livestock are present at the farm, and whether the livestock on the farm are pastured or confined (or both). Appendix table H1 shows the practices assumed by type of farm.

(6) *Costs of other baseline practices to producer=Financial assistance rate × Actual cost of other practices*

The costs of generating credits include the yield costs from reducing nutrient application below agronomic rates, and reducing application of fertilizer and/or manure:

(7) *Costs of generating credits=Yield costs + Fertilizer reduction costs + Manure reduction costs*

Under the simulated program, the producer reduces nutrient applications by 15 percent by either reducing the amount of fertilizer applied or by shipping manure off-farm. Reducing fertilizer will occur by purchasing less, thereby reducing costs (the "fertilizer reduction costs" will be negative in equation 7). The fertilizer reduction costs will depend on the unit cost of fertilizer and the amount applied. Reducing manure occurs by shipping it off-farm, thereby raising costs. Manure reduction costs are the per-unit costs of shipping manure times the amount of manure shipped off-farm.[25] We assume that producers that do not generate recoverable manure apply at least 15 percent of their nutrients in the form of commercial fertilizer. A farm that generates recoverable manure is assumed to meet its nutrient needs first with manure. If it has additional nutrient needs, it is assumed to meet these with fertilizer. Farms with both fertilizer and manure will first reduce fertilizer (thus decreasing costs) then manure (thus increasing costs).

In three of the four Chesapeake Bay States with nutrient trading programs, an NMP is required to meet the baseline (Maryland, Virginia, and West Virginia). An NMP requires that a producer apply nutrients in an agronomic fashion, so the 15-percent reduction in nutrient application to cropland will mean reducing applications below rates required in an NMP. We assume that the reduction in nutrient applications beyond agronomic rates will lower yields and that elemental nitrogen and phosphorus from fertilizer are completely substitutable for elemental nitrogen and phosphorus from manure.[26] Thus, the cost of generating credits also includes the costs of lost yields.

The cost of generating credits will therefore be a function of the yields in different crops, the price per unit of crops, and the reduction in yields from a 15-percent reduction in nutrients (the yield reduction factor). For a single crop, this is:

---

[25] We assume different costs per unit of manure shipping for wet versus dry manure, and we vary the assumed shipping distances according to sub-watershed. See appendix H.

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

(8) $\text{Yield costs} = \text{Yield reduction factor} \times \text{Price per unit of crop} \times \text{Yield from crop}$

Since farms grow multiple crops, the total yield costs will be the sum of all yield costs for all crops grown on the farm.

How much meeting the baseline, yield losses, fertilizer reductions, and manure shipping affect the net value of credits depends on their relative costs and the benefits generated from selling credits. To provide some understanding of these relative costs, we parameterize the model using information from a variety of sources and apply it to 2012 Census of Agriculture data for Chesapeake Bay watershed counties (see tables 13 and 14 for parameter values and other model assumption; see appendix H for more detail). We 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 incorporating variations from the "base" scenario. We also estimate the credit price at which the average producer would enter nutrient trading. We estimate the percentage of nutrients reduced from current application levels by credit price and type of farm. Finally, we conduct 18 sensitivity analyses to examine the changes in outcomes when assumptions or parameter values are altered.

Table 13

Model parameters, "base" scenario values, justifications, and sensitivity analyses

Parameter	"Base" scenario	Justification	Sensitivity analyses
Credit price	$20 per pound (lb) of nutrient (nitrogen (N) or phosphorus (P))	World Resources Institute publications about nutrient trading in the Chesapeake Bay discusses a $20/lb of N trading price in a fully developed market (Talberth et al., 2010a and 2010b)	Vary credit price from $0 to $300
Trading ratio	2:1 (trading ratio factor = 0.5)	Virginia uses a 2:1 uncertainty ratio; the EPA guidance document uses a 2:1 trading ratio in nearly all examples (VA DEQ, undated; U.S. EPA, 2009b).	1:1, 3:1 (trading ratio factors of 1 and 0.33)
Reduction in yields from 15-percent reduction in nutrient applications	10 percent	Actual yield loss will vary depending on crop type, soil type, and precipitation. Since we do not have information on these variables for each factor, we make the assumption of a 10-percent yield reduction (Bongard, 2012).	0 percent, 5 percent, 15 percent
Transaction costs	40 percent of baseline practice costs, exclusive of manure shipping	The Chesapeake Bay Commission (2012), in a review of the literature on transaction costs, finds a range of 10- to 50-percent transaction costs. They apply 38 percent of the cost of BMPs as their transaction costs.	10 percent, 50 percent
Financial assistance share	50 percent	EQIP shares are often around 50 percent. In MD, PA, VA, and WV, BMPs generated through public financial assistance may be used to meet baseline practices (Branosky et al., 2011; Ribaudo et al., 2014).	0 percent , 75 percent

- continued

Table 13

Model parameters, “base” scenario values, justifications, and sensitivity analyses - continued

Parameter	“Base” scenario	Justification	Sensitivity analyses
Whether large CAFOs have permits before nutrient trading	Large CAFOs in States other than Maryland, Virginia, and Delaware do not have permits, and therefore do not have NMPs before entering nutrient trading.	EPA data from 2013 show that less than half of CAFOs in the Chesapeake Bay States had permits (U.S. EPA, 2013).	Large CAFOs in states other than Maryland, Virginia, and Delaware do have permits and therefore NMPs before entering nutrient trading.
Whether AFOs have NMPs before nutrient trading	All AFOs in Maryland, Virginia, and Delaware have NMPs; hence, they are assumed to have already paid for NMP development costs and the manure shipping costs of any excess manure nutrients generated onfarm.	Maryland, Virginia, and Delware require NMPs for all AFOs (Perez, 2011).	
Manure miles shipped	Loading cost plus ton/mile shipping costs. Distance shipped is subwatershed-specific and assumes non-livestock producers would accept 50 percent of manure shipped.	Miles shipped by subwatershed factors in the fact that the amount of spreadable crop acreage differs by watershed. Distances are from Ribaudo et al., 2014. Load costs and ton/miles costs are from Ribuado et al., 2003.	First variant: Subwatershed-specific miles assuming non-livestock producers would accept 30 percent of manure shipped. Second variant: Sub-watershed-specific miles assuming non-livestock producers would accept 50 percent of manure shipped, with dry manure being moved double this distance and wet manure being moved half of it.
Costs of baseline practices other than implementation of NMP	See appendix table H1 for specific practices and costs by type of farm.	Costs for requirements to meet the nutrient trading baseline arise from a World Resources Institute examination of best management practices used in the Chesapeake Bay. Information on these practices and this data gathering can be found in Ribaudo et al., 2014.	
Fertilizer prices	2012 values from USDA/NASS	Census of Agriculture data are from 2012	2007, 2009 values from USDA/NASS
Crop prices	2012 values from USDA/NASS	Census of Agriculture data are from 2012	2007, 2009 values from USDA/NASS

BMPs = best management practices.

EQIP = USDA, Environmental Quality Incentives Program.

AFO = animal feeding operation; CAFO = confined animal feeding operation.

EPA = Environmental Protection Agency.

NMP = nutrient management plan.

USDA/NASS = USDA, National Agricultural Statistics Service.

Source: USDA, Economic Research Service.

Table 14

Other model assumptions, justifications, and sensitivity analyses

"Base" scenario	Justification	Sensitivity analyses
Livestock operators who ship manure off-farm are not paid for the manure nutrients	Prior analyses by Ribaudo et al. (2014), who model Chesapeake Bay farmers' "willingness-to-accept" manure, rather than any price they were willing to pay for it.	Livestock operators can sell their manure nutrients. The value of manure nutrients is set at the same price as the value of the fertilizer nutrients (in 2012 dollars). However, producers shipping manure still need to pay for the cost of shipping the manure. Hence, the value of the manure nutrients is the revenue received minus the shipping cost.
Livestock operators cannot generate nutrient credits when they ship manure off-farm to meet their NMP, part of baseline requirements	Baseline practices are not generally counted toward generation of credits, in order to satisfy discharge reductions from agriculture and guarantee additionality.	Livestock operators can generate nutrient credits when they ship manure off-farm to meet their NMP, part of baseline requirements.

NMP = nutrient management plan.

Source: USDA, Economic Research Service.

Simulation results

Simple expository simulations of comparison farms

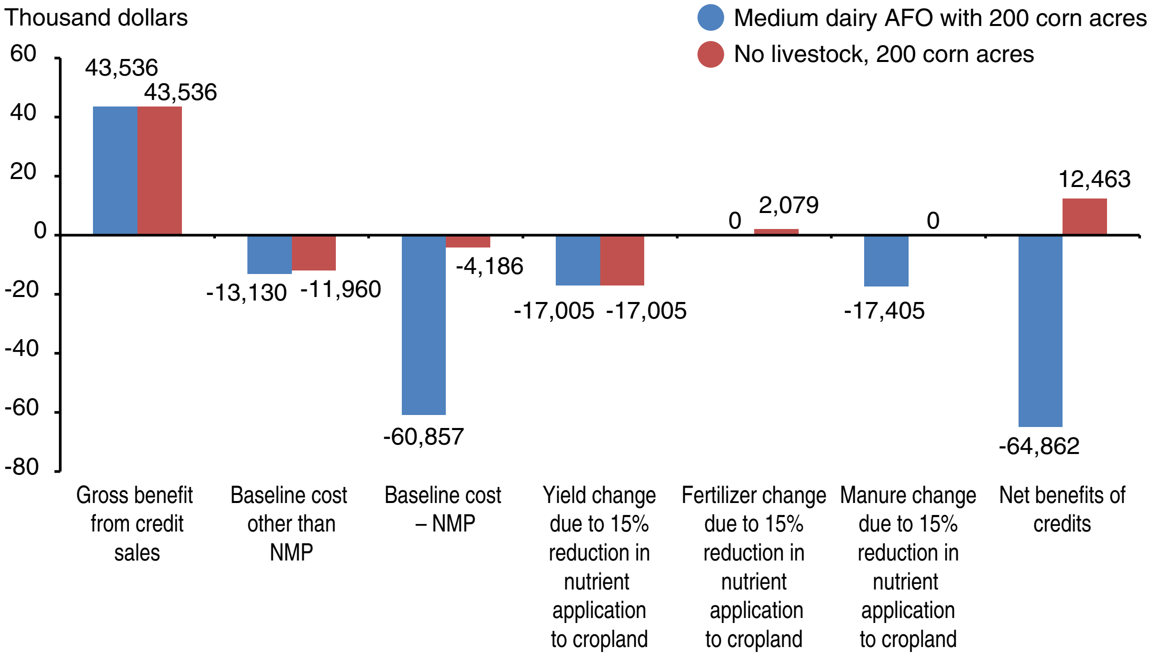
For exposition purposes, we first conduct three simple simulations comparing two farms using the parameters and assumptions found in tables 13 and 14 for the "base" scenario.[27] In the first simulation, we compare a medium-sized dairy AFO with 400 cows and 200 acres of corn with a farm with no livestock and 200 acres of corn. In this scenario, the dairy operation produces more manure nutrients than it can assimilate on its crops. Figure 18 compares the benefits and costs of participation for the two farms in a nutrient trading program using a 15-percent reduction in nutrient applications to cropland to generate credits. Both farms reduce the same amount of nitrogen and therefore produce the same number of credits to sell; hence, their gross benefit from credit sales is equal ($43,536). Because both farms produce only corn, the loss in yields will be the same, as will the cost of this yield loss (a loss of $17,005). To install best management practices (BMP) other than the NMP required to meet the baseline, the dairy farm pays $13,130 while the crop-only farm pays $11,960. The small difference arises due to assumptions that the dairy farm must institute different BMPs related to livestock. Because the dairy AFO is predicted to be unable to use all of the manure it produces on its corn, it must ship manure off-farm as part of meeting the NMP. Hence, the NMP cost for the dairy is $60,857 while that for the crop-only farmer is just $4,186. The crop-only farmer is assumed to use just fertilizer to meet the farm's nitrogen needs; hence, reduction in fertilizer purchases will save the crop-only farmer $2,079. Because the dairy producer already generates more manure nitrogen than needed for the farm's corn needs, he/she is assumed to not purchase any nitrogen fertilizer, and therefore has no change in fertilizer costs. To generate credits by reducing nitrogen applications by 15 percent below agronomic needs, the dairy producer must ship even more manure off-farm, costing an additional $17,405. The crop-only producer does not generate any manure, and therefore has no manure shipping costs. Subtracting the various costs from the gross benefits, the net benefit from credit sales will be negative for the dairy operation (negative $64,862), in large part because of the costs to meet the baseline. The crop-only farmer sees a positive net

---

[27] Also see appendix I for the exact calculations for the first simulation.

Figure 18

Comparison of nutrient credit benefits for example crop-only versus livestock producer with excess nutrient production (simulation 1)



AFO = animal feeding operation.
NMP = nutrient management plan.
Source: USDA, Economic Research Service.

benefit from participation of $12,463. In this scenario, the crop-only producer would find nutrient trading cost-beneficial, while the dairy operation would not.

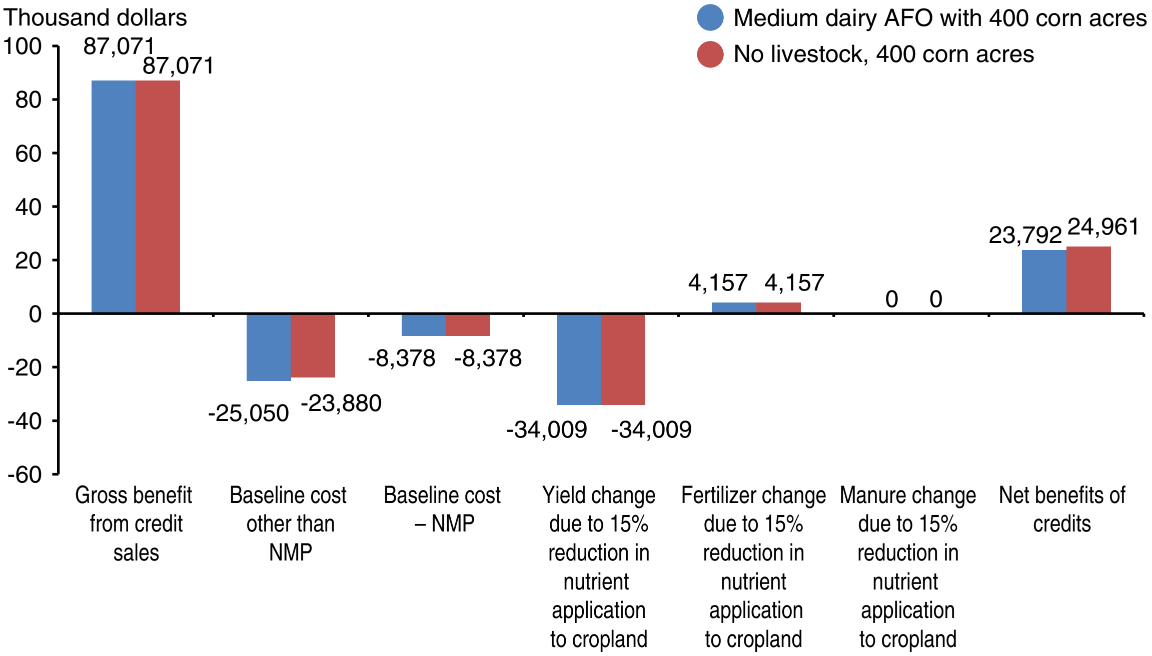
In the second simulation, we again compare two farms with the same acreage (fig. 19). However, in this case, both farms have 400 acres of corn cropland, while the dairy operation still has 400 cows. This means that the dairy operation has enough land on which to assimilate all of its manure nutrients, and it is further assumed to purchase fertilizer as it does not produce enough manure nutrients to meet all of its crop nutrient needs.[28] The dairy operation can meet the 15-percent application reduction by reducing just fertilizer, and it does not need to ship any manure off farm to meet the NMP. Hence, the AFO does not see any differences from the crop-only producer from meeting the NMP as part of the baseline or in manure shipping costs. As a result, the two farms see similar net benefits from participating in nutrient trading.

---

[28] The corn yield from 400 acres is predicted to be 49,360 bushels. The estimated uptake from this corn is 58,047 pounds of nitrogen. The dairy cows are again predicted to generate 43,199 lb of recoverable nitrogen; to meet its nitrogen needs, the dairy operation is assumed to purchase 14,849 lb of nitrogen fertilizer. As 15 percent of the uptake capacity is 8,707, the dairy operation can satisfy the 15-percent reduction in N applications to cropland by reducing just fertilizer.

Figure 19

Comparison of nutrient credit benefits for example crop-only versus livestock producer without excess nutrient production (simulation 2)



AFO = animal feeding operation.
NMP = nutrient management plan.
Source: USDA, Economic Research Service.

Potential participants in nutrient trading via a 15-percent reduction in nutrient applications to cropland, after meeting baseline requirements

Turning to the analysis of all farms in the Chesapeake Bay watershed, we start by examining some characteristics of farms that are potential participants in nutrient trading via a 15-percent reduction in nutrient applications to cropland. To be a potential participant, a farm must have some assimilative capacity for nutrients on crops; in terms of the simulation, a farm would need to have a non-zero yield in 1 of 23 crops. Table 15 shows that only 61 percent of operations in the Bay are potential participants on this basis. Farms that are excluded either grow crops in other (far less common) commodities, or they just have pasture (but not crop) acreage. AFOs with excess manure nutrients are also less likely to be potential participants. Because these farms have no cropland, they have no ability to apply recoverable manure on the farm (yielding excess) and they cannot reduce any applications in order to generate credits under this simulated program.

To provide some perspective on what may influence relative participation in nutrient trading, table 16 shows the average values for the variables used to estimate participation for each farm. The value of crops grown will influence the cost of the yields lost from nutrient trading participation. The crop uptake capacity will influence the number of credits that can be generated. The table also shows the average amount of manure nutrients recovered and the assumed amount of nutrient fertilizer applied. These values are important because they influence the costs of manure shipping as well as fertilizer costs saved. AFOs with excess manure nutrients are assumed to not apply any fertilizer.

Table 15

Summary statistics of potential participants in nutrient trading via a 15-percent reduction in nutrient applications to cropland, by farm type

	All farms in category that are potential participants	Potential participants—operations with any nutrient assimilative capacity on crops			
		Farms	Total value of crops grown	Total amount of crops	Total amount of pasture
	Percent	Number	Dollars	Acres	
All	**61**	**63,867**	**83,644**	**8,885,900**	**3,450,532**
No livestock – Less than 100 acres of cropland	47	13,265	14,250	725,432	272,340
No livestock – 100 or more acres of cropland	86	5,344	316,123	2,660,333	122,032
Some livestock but not likely to be confined	58	32,128	31,582	2,407,588	2,419,233
Small animal feeding operation (AFOs)	90	10,956	139,424	2,021,876	445,968
Without excess	100	10,309	147,213	1,989,660	350,038
With excess	35	647	15,328	32,216	95,930
Medium AFOs	67	1,759	344,194	732,696	141,613
Without excess	100	961	594,418	668,837	56,155
With excess	48	798	42,859	63,859	85,458
Large AFOs	67	415	761,636	337,975	49,346
Without excess	100	194	1,487,885	298,331	15,046
With excess	51	221	124,115	39,644	34,300

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

AFOs without excess manure nitrogen apply enough fertilizer that they could meet the 15-percent application reduction just through reducing fertilizer. For example, the average small AFO without excess nitrogen has a crop uptake capacity of 41,274 lb of nitrogen, but it only generates 5,562 lb of manure nitrogen. Hence, it is assumed to apply fertilizer for the remaining crop needs (36,496 lb). Since 36,496 is greater than 15 percent of 41,274, the average small AFO without excess can satisfy the 15-percent reduction in nutrient applications to cropland by just reducing fertilizer. It would therefore operate in a nutrient trading program focused on reductions in nutrient applications to crops in much the same way as crop-only operations. AFOs that generate excess manure nutrients would, however, see the additional costs of manure shipping.

Notably, operations with excess onfarm nutrients realize less income from crops (see table 15). This is because they have less crop acreage overall and less uptake capacity (contributing to their having excess nutrients in the first place). This will impact these farms' benefits from instituting a crop-based intervention like a 15-percent reduction in nutrient applications to cropland. With less uptake capacity, a 15-percent reduction in nutrient application will generate fewer credits; if a farm has 100 lb of nitrogen uptake capacity, a 15-percent reduction is 15 lb, while farms with 1,000 lb of nitrogen uptake capacity can reduce 150 lb. Since credits are based on the amount of nitrogen reduced, the farm with more uptake capacity will be able to generate more credits.

The bottom panel of table 16 shows similar values for possible participants in nutrient trading based on phosphorus. Notably, the amounts of phosphorus uptake are much lower than those for nitrogen. Thus, operations reducing 15 percent of their phosphorus applications will generate many fewer credits than a 15-percent reduction in nitrogen applications.

Table 16

Average values of variables used in model, by farm type

	Potential participants—operations with any nitrogen (N) assimilative capacity on crops			
	Crop N uptake capacity	Pasture N uptake capacity	Manure N recovered	N fertilizer applied
	Pounds			
	Number	Dollars	Acres	
All	**24,968**	**724**	**2,682**	**23,715**
No livestock – Less than 100 acres of cropland	4,203	180	0	4,383
No livestock – 100 or more acres of cropland	97,676	395	0	98,071
Some livestock but not likely to be confined	10,466	935	0	11,402
Small animal feeding operations (AFOs)	39,065	759	5,821	34,341
Without excess	41,274	784	5,562	36,496
With excess	3,872	355	9,944	0
Medium AFOs	91,270	1,455	34,840	69,956
Without excess	157,493	1,863	31,310	128,046
With excess	11,521	964	39,092	0
Large AFOs	221,868	2,002	111,380	160,877
Without excess	438,600	2,891	97,347	344,144
With excess	31,615	1,222	123,698	0

	Potential participants—operations with any phosphorus (P) assimilative capacity on crops			
	Crop P uptake capacity	Pasture P uptake capacity	Manure P recovered	P fertilizer applied
	Pounds			
	Number	Dollars	Acres	
All	**2,847**	**267**	**1,199**	**2,458**
No livestock – Less than 100 acres of cropland	473	66	0	539
No livestock – 100 or more acres of cropland	11,449	146	0	11,595
Some livestock but not likely to be confined	1,237	345	0	1,582
Small animal feeding operations (AFOs)	4,246	280	2,529	2,453
Without excess	5,450	339	2,289	3,500
With excess	1,427	143	3,092	0
Medium AFOs	10,056	537	16,030	3,904
Without excess	26,291	922	13,450	13,762
With excess	3,626	385	17,051	0
Large AFOs	25,072	739	49,875	7,999
Without excess	84,318	1,602	46,401	39,519
With excess	10,036	520	50,757	0

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

Simulation results for all farms in the Chesapeake Bay watershed

Table 17 provides estimates of participation in and costs of a 15-percent reduction in nutrient applications to cropland to generate nitrogen 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 model variables for all possible participants in nutrient trading (those with an estimated non-zero nitrogen assimilative capacity for 21 crops).

Of possible participants, 62 percent find nutrient trading to be cost-beneficial, but this likelihood varies by type of farm. Crop-only farms with at least 100 acres and AFOs without excess nitrogen are the most likely to participate (between 93 and 92 percent). Small AFOs with excess manure nitrogen are the least likely to be possible participants (see table 15), and when they are possible participants, they are the least likely to find participation cost-beneficial (see table 17). Medium and large AFOs with excess nitrogen also have low probabilities of finding participation cost-beneficial, and even when they do, the net value of credits is comparably low.

Changes in fertilizer and manure shipping costs are relatively small compared to the cost of changes in yields. Small and medium AFOs save less in fertilizer expenses than large crop-only farms but more than small crop farms or pasture-based livestock operations when instituting a 15-percent reduction in nutrient applications to cropland. While AFOs pay more in manure export costs, these additional costs are on average very low.

What hurts the participation of AFOs with excess nitrogen the most is the fact that they do not have a great deal of nutrient uptake capacity and therefore do not have a lot to reduce. Thus, they cannot generate many credits, and their benefit from doing so is not often great enough to offset their costs from participation.

If credits were based on phosphorus instead of nitrogen, participation across all types of farms would be extremely low. Table 18 shows estimates of participation and costs when each phosphorus credit is valued at $20. Less than 1 percent of farms find it cost-beneficial to participate, and the average net value of credits is negative. This is because the amount of phosphorus used by crops is much lower than the amount of nitrogen; therefore, the number of credits and their gross value is much lower, even while the costs of participation not pertaining to yield changes are similar.

Table 17

Predicted participation in nutrient trading via a 15-percent reduction in land application of nitrogen to cropland, by type of agricultural operation

Type of farm	Of all possible participants: Farms that find 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
	Percent	Dollars						
All	**62**	**19,415**	**37,452**	**9,153**	**2,271**	**8,364**	**-1,767**	**15**
No livestock – Less than 100 acres of cropland	73	2,725	6,305	1,828	628	1,425	-301	0
No livestock – 100 or more acres of cropland	93	83,494	146,514	28,427	9,976	31,612	-6,995	0
Some livestock but not likely to be confined	43	5,534	15,700	6,524	1,233	3,158	-750	0
Small animal feeding operations (AFOs)	89	32,747	58,598	12,164	2,522	13,942	-2,788	9
Without excess	92	34,820	61,911	12,690	2,642	14,721	-2,962	0
With excess	35	-274	5,808	3,777	614	1,533	0	159
Medium AFOs	79	76,525	136,905	26,216	5,601	34,419	-6,156	299
Without excess	99	138,685	236,239	41,969	7,403	59,442	-11,267	7
With excess	54	1,669	17,281	7,245	3,432	4,286	0	650
Large AFOs	78	208,315	332,803	46,797	15,250	76,164	-14,555	833
Without excess	100	436,311	657,900	84,690	19,131	148,789	-31,137	116
With excess	59	8,174	47,423	13,533	11,843	12,411	0	1,461

BMP = best management practices.

NMP = nutrient management plan.

Note: Assumes a value of nitrogen credits of $20 per pound. Possible participants include just those farms with non-zero nitrogen uptake capacity in at least one of 21 different crops. Farm categories based on crop acreage are for farms that had acreage in any cropland, not just the 21 crops under analysis.

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

Table 18

Predicted participation in nutrient trading via a 15-percent reduction in land application of phosphorus to cropland, by type of agricultural operation

Type of farm	Of all possible participants: Farms that find 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
	Percent	Dollars						
All	**0.11**	**-15,184**	**4,270**	**9,153**	**2,208**	**8,364**	**-282**	**11**
No livestock – Less than 100 acres of cropland	0.07	-3,120	709	1,828	628	1,425	-51	0
No livestock – 100 or more acres of cropland	0.65	-51,600	17,174	28,427	9,976	31,612	-1,241	0
Some livestock but not likely to be confined	0.06	-8,925	1,856	6,524	1,233	3,158	-134	0
Small animal feeding operations (AFOs)	0.03	-21,565	6,370	12,164	2,213	13,942	-394	10
Without excess	0.04	-26,891	8,175	14,817	3,036	17,777	-562	-2
With excess	0	-9,092	2,141	5,949	286	4,960	0	38
Medium AFOs	0	-50,463	15,083	26,216	5,462	34,419	-764	214
Without excess	0	-118,573	39,436	59,719	10,592	90,376	-2,693	16
With excess	0	-23,490	5,439	12,948	3,430	12,259	0	292
Large AFOs	0.72	-98,423	37,608	46,797	14,228	76,164	-1,693	535
Without excess	3.57	-260,770	126,477	124,784	27,606	243,105	-8,364	117
With excess	0	-57,223	15,055	27,006	10,833	33,798	0	641

BMP = best management practices.

NMP = nutrient management plan.

Note: Assumes a value of phosphorus credits of $20 per pound. Possible participants include just those farms with non-zero phosphorus uptake capacity in at least one of 21 different crops. Farm categories based on crop acreage are for farms that had acreage in any cropland, not just the 21 crops under analysis.

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

Sensitivity analyses

We conduct 18 sensitivity analyses, altering 1 assumption or parameter in each test. Recall that the baseline assumptions are as follows:

- A $20 nitrogen credit price
- A 10-percent loss in yield from the 15-percent reduction in nitrogen application
- Manure shipping costs as detailed in appendix H
- 40-percent transactions costs on baseline requirements exclusive of manure shipping
- Large AFOs outside of Maryland, Virginia, and Delaware have not yet been permitted and therefore have to bear the costs of satisfying the baseline requirements as part of participation in nutrient management.
- 2012 crop prices
- 2012 fertilizer prices
- 50-percent financial assistance share for baseline requirements aside from manure shipping
- Manure shipped off-farm is received without payment.
- Shipping manure off-farm to meet the NMP does not generate nutrient credits.

In the sensitivity analyses, we vary one of these assumptions in each test:

- Manure shipped off-farm to satisfy the NMP can be used to generate credits.
- Manure can be sold at the same price as fertilizer (although shipping costs remain the same).
- There are no transaction costs on baseline requirements.
- The trading ratio is 1:1, meaning the trading ratio factor is 1.
- The trading ratio is 3:1, meaning the trading ratio factor is 0.33.
- The financial assistance share level for baseline requirements is 0 percent; farmers cannot use any financial assistance to help them pay for baseline requirements.
- The financial assistance share level for baseline requirements is 75 percent; farmers only see 25 percent of the actual costs of baseline practices.
- A 0-percent loss in yield from the 15-percent reduction in nutrients below agronomically appropriate rates
- A 5-percent loss in yield from the 15-percent reduction in nutrients below agronomically appropriate rates
- A 15-percent loss in yield from the 15-percent reduction in nutrients below agronomically appropriate rates
- Fifty-percent transaction costs on baseline requirements exclusive of manure shipping
- Alternative manure-shipping distances 1: Manure-shipping distances assuming a 30-percent willingness to accept manure by crop producers
- Alternative manure-shipping distances 2: Manure-shipping distances assuming a 50-percent willingness to accept manure by crop producers, doubling this distance for poultry manure and halving it for other types of manure
- 2007 crop prices (updated to 2012 dollars)
- 2009 crop prices (updated to 2012 dollars)

- 2007 fertilizer prices (updated to 2012 dollars)
- 2009 fertilizer prices (updated to 2012 dollars)
- Large AFOs in all States are already permitted, so they are assumed to already have a nutrient management plan in place and do not have these additional costs in order to participate in nutrient trading.

The results of altering these assumptions vary. The first 7 sensitivity analyses alter results the most; table 19 shows the results of these 7 sensitivity analyses, while results from the other 10 can be found in appendix J. In the first sensitivity analysis, we allow credits to be generated as part of shipping manure off-farm when satisfying the NMP.[29] This violates rules as laid out by the three States with nutrient trading programs that require a NMP to meet the baseline. However, it is a possible stipulation that could be allowed to encourage participation by AFOs with excess manure. Changing this assumption has a marked effect on the willingness to participate of AFOs with excess manure nutrients. If this assumption is changed, nearly all AFOs find it cost-beneficial to participate.

Having a small positive price on manure nitrogen also increases the likelihood that AFOs will participate in nutrient trading. Note that in this scenario, farms can sell manure nutrients for the same price as fertilizer nutrients, but they must still pay shipping costs. These results also reflect the cost of a small subsidy for manure shipping.

The other four sensitivity analyses shown in table 19 alter likelihood of participation in the same manner for all types of farms. Changing the trading ratio to 1:1 means that each reduction will count toward more credits, hence more revenue; this increases the likelihood of participation for all types of farms. Similarly, changing the trading ratio to 3:1 means that each reduction will lead to fewer credits generated and less revenue from participation; this decreases the percentage of operations finding it cost-beneficial to participate.

The amount of financial assistance also has a significant impact on the percentage of operations finding nutrient trading cost-beneficial. Without the ability to pay for baseline requirements with financial assistance, the percentage of operations finding it cost-beneficial to participate drops from 62 percent to 38 percent. If the financial assistance percentage is increased to 75 percent (meaning that farmers only bear 25 percent of the actual costs of baseline requirements), then participation increases. Noticeably, AFOs with excess manure nutrients are still the least likely to participate in trades.

In the 11 other sensitivity analyses (appendix table J1), altering parameter values and assumptions does little to alter the likelihood of participation, compared to the "base" scenario. In all sensitivity analyses, AFOs with excess manure nutrients 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 0 or 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 crop and fertilizer prices and manure shipping distances cause little change in the estimates. Assuming that large AFOs are already regulated and therefore already meet most baseline requirements does increase the percentage of these operations finding it cost-beneficial to participate.

---

[29] Pennsylvania allows poultry producers to generate credits by shipping litter out of the watershed. The generation of credits can only take place after the farm meets applicable regulations, including stipulations on land application of manure. However, Pennsylvania does not require a nutrient management plan for all farms as a baseline requirement (only CAFOs) (Pennsylvania Department of Environmental Protection, 2015). We do not model trading with these stipulations in this report.

Table 19

Sensitivity analyses: Effects of parameter and assumption changes from "base" scenario on percentage of possible participants finding it cost-beneficial to participate

	Change in parameter or assumption from "base" scenario								
Type of farm	"Base" Scenario	Credits from shipping manure off-farm when meeting NMP	Manure price set at same level as fertilizer price (2012)	No transaction costs on baseline requirements	Trading ratio 1:1	Trading ratio 3:1	0 percent financial assistance for baseline practices	75 percent financial assistance share for baseline practices	Average change in manure shipping costs to generate credits
	Percent								
All	**62**	**64**	**63**	**73**	**83**	**43**	**38**	**81**	**11**
No livestock – Less than 100 acres of cropland	73	73	73	86	92	45	37	91	0
No livestock – 100 or more acres of cropland	93	93	93	97	99	71	60	98	0
Some livestock but not likely to be confined	43	43	43	56	72	27	23	69	0
Small AFOs	89	92	89	94	97	72	67	96	10
Without excess	92	92	92	97	99	76	70	99	-2
With excess	35	95	44	47	65	15	12	58	38
Medium AFOs	79	100	86	82	89	63	60	86	214
Without excess	99	99	99	100	100	94	90	100	16
With excess	54	100	71	62	76	26	25	69	292
Large AFOs	78	100	90	81	89	62	61	85	535
Without excess	100	100	100	100	100	97	94	100	117
With excess	59	100	81	65	79	32	33	71	641

NMP = nutrient management plan.

AFO = animal feeding operation.

Note: Baseline scenario: $20 credit price, 10-percent loss in yield from enhanced nutrient management, 40-percent transactions costs, "base" scenario manure shipping distances (see appendix H), trading ratio of 2:1, 2012 crop prices, 2012 fertilizer prices, 50-percent financial assistance share for baseline practices, large CAFOs do not have prior regulation, manure can only be given away (not sold), and shipping manure off-farm to meet the NMP does not generate credits.

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

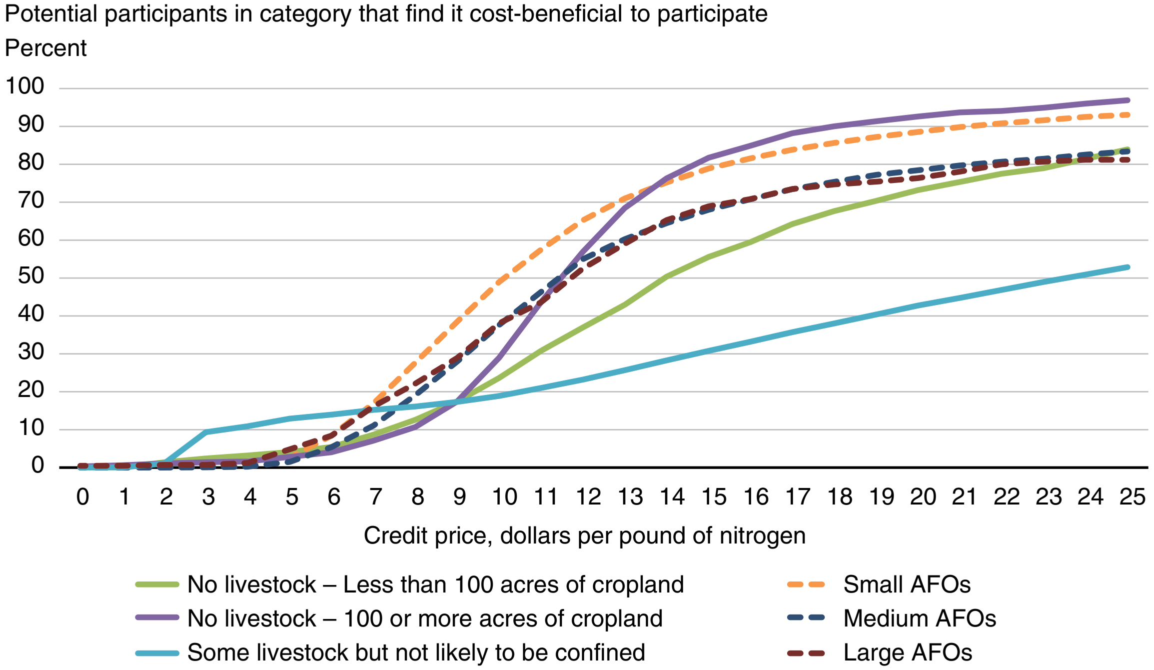
Participation and credits generated at various credit prices

The baseline credit price is $20 per credit, reflecting a fully developed nutrient-trading market. However, nutrient-trading markets in Chesapeake Bay States have thus far seen very few trades and much lower credit prices. We therefore explore what percentage of possible participants would enter the simulated nutrient trading program and what would be the number of credits generated at various nitrogen credit prices between $0 and $25. Figure 20 shows the percentage of potential participants by category that would find entering the simulated nutrient-trading program cost-beneficial at different nitrogen credit prices. Up to about $6 per credit, most operations of all categories would not find it cost-beneficial to participate. Between about $6 and $14, participation rates for most categories of farms rise quickly.

Even if few farms participate at specific credit prices, the farms participating may generate many credits, signifying reductions in many pounds of nutrient applications. Figure 21 shows the number of nitrogen credits generated at various credit prices, by category of operation. Even at a credit price of $0, there are a few farms that would participate; this is the case because their modeled yield reduction and baseline costs are lower than the amount they would save by reducing nutrient applications via fertilizer or manure.[30] The number of credits generated reflects the number of operations in the category as well as the pounds of nitrogen applications reduced per farm. Hence, at credit prices above $11, the most credits are generated by large crop-only operations and small AFOs. While pasture-based operations ("some livestock but not likely to be confined") have the lowest participation rates at credit prices over $10 (figure 20), they still are numerous enough and produce enough credits per farm to generate the third largest amount of credits at these prices.

Figure 20

Proportion of possible participants that find it cost-beneficial to participate in simulated nutrient trading program, by type of operation and nitrogen credit price



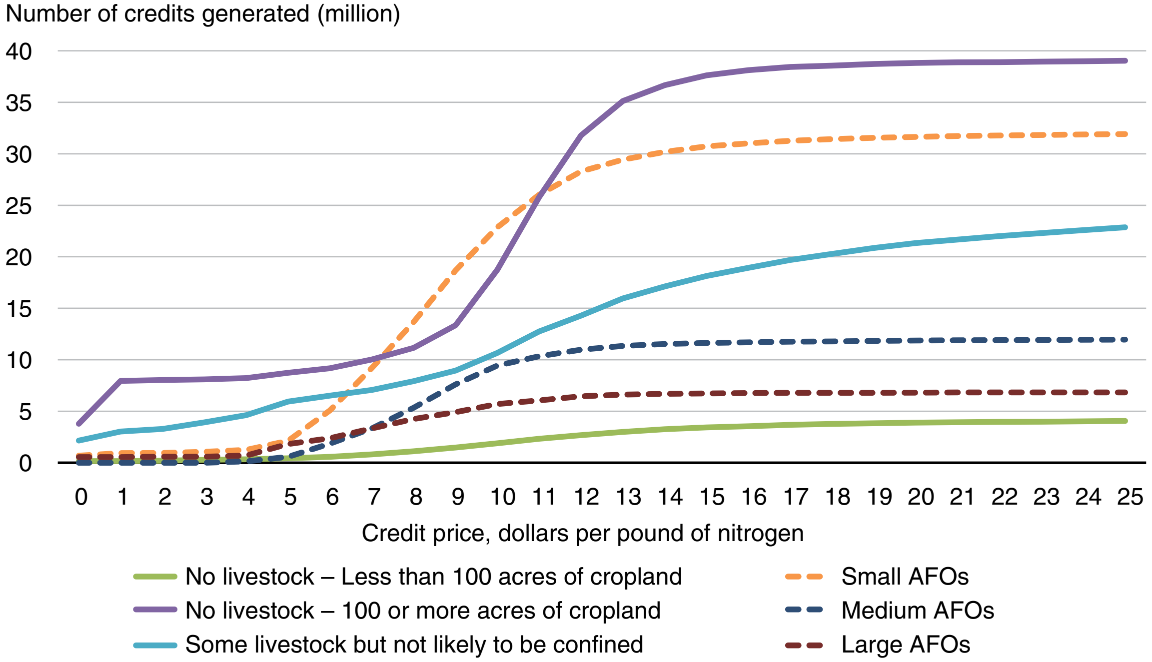
AFO = animal feeding operation.
Source: USDA, Economic Research Service.

---

[30] Note that the number of operations for which this is the case is estimate to be only 39; this amounts to 0.04 percent of farms in the Chesapeake Bay watershed.

Figure 21

Total number of credits generated by participants in simulated nutrient trading program, by type of operation and nitrogen credit price



AFO = animal feeding operation.
Source: USDA, Economic Research Service.

Credit prices needed to reduce excesses and incentivize participation

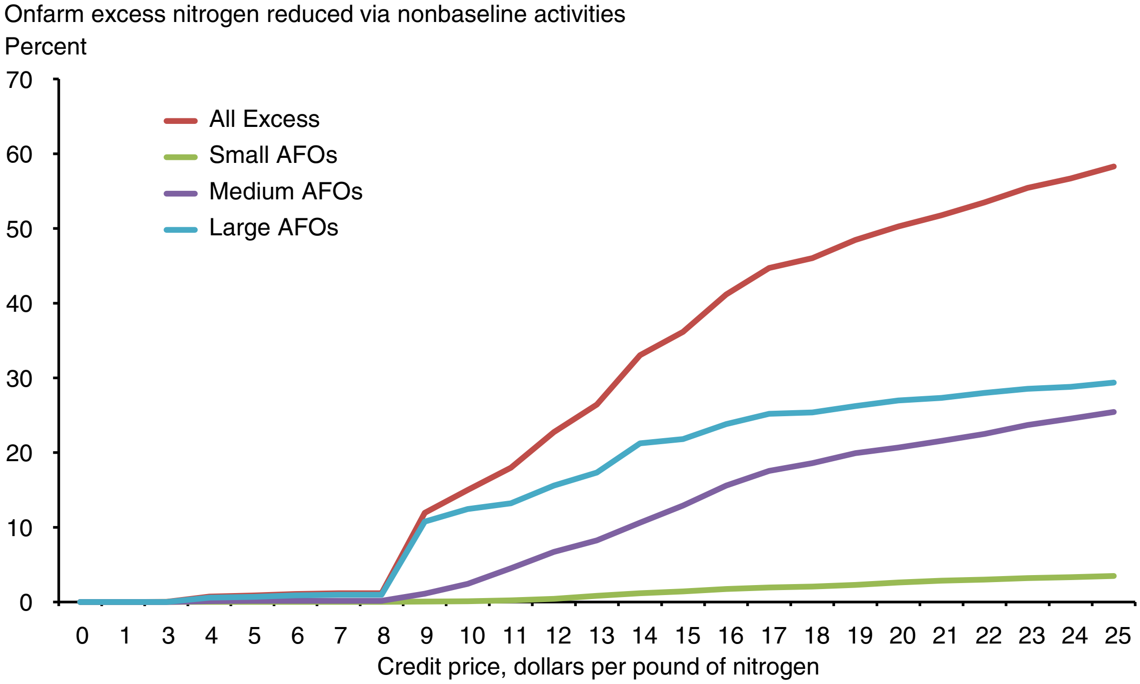
What would credit prices need to be to have AFOs with excess onfarm nutrients participate and reduce excesses? Figure 22 shows the percentage of onfarm excess nitrogen reduced at each credit price. At the "base" credit price of $20/credit, 50 percent of onfarm excess nitrogen is reduced, mainly from large AFOs. The percent reduction increases with price, but even at a value of $100/credit, the share of onfarm excess nitrogen reduced is still only 89 percent.

What price would be required for the average farm of each type to participate in nutrient trading? Table 20 shows the "break-even" price for nutrient credits at which the average farm would find nutrient trading cost-beneficial. For nitrogen-based credits, this value is $31 across all farms. However, it is much higher for AFOs with excess nutrients. The value for phosphorus-based credits is nearly nine times higher across all farms ($268/credit); again, this is because there is much less phosphorus uptake capacity used by crops, and therefore a 15-percent reduction in phosphorus applications yields much fewer credits.

These results suggest that trading systems that are strongly reliant on credit generation from reduction in land application of nutrients may not induce AFOs with excess onfarm nutrients to participate, unless credit prices are higher, manure nutrients can be sold for a positive price, or credits can be generated from shipping manure off-farm as part of satisfying the baseline NMP. Higher prices could be obtained by making the TMDL more strict, thereby requiring point sources to either institute more expensive technologies or enter nutrient trading willing to pay higher credit prices. A positive price for manure could be generated through a subsidy or by support for non-agricultural uses of litter or manure, such as burning for electricity generation or pelletizing for non-agricultural landscaping. Several proposals have been made to use manure in the Chesapeake Bay for biomass energy, but support has been limited (Ribuado et al., 2014).

Figure 22

Percentage of onfarm excess nitrogen reduced through nutrient trading participation via a 15-percent reduction in nitrogen application to cropland



AFO = animal feeding operation.
Source: USDA, Economic Research Service.

Allowing credits to be generated via shipping excess manure nutrients off-farm to meet the NMP baseline requirement would entail a change in certain trading stipulations laid out by the EPA and the Chesapeake Bay Commission. This would also reward producers with a higher potential to pollute and create an incentive to generate excess nutrients either by having more animals or reducing land application area. Changing this trading stipulation would require careful consideration of how to monitor excess, both over time at an individual farm and across farms.

A trading scheme in which credits could be generated via other means might more readily induce AFOs with excess manure nutrients to participate. Because the focus of this report is comparing crop and livestock producer participation in nutrient trading, we do not model other potential methods of credit generation that would only be applicable to livestock producers. Credits could be generated, for example, by shipping not just excess manure off-farm, but all manure. Modeling such a system would require assumptions on “leakage” prevention; for example, would the livestock producer be allowed to ship manure off-farm but replace it with fertilizer, leading to no net reduction in nutrients in the watershed? Such a system would also need to take into account the differential yield costs from reducing nutrients on differently valued crops. This is an area for future research.

Table 20

Average break-even price[1] at which farms find it cost-beneficial to participate in nutrient trading

	Nitrogen	Phosphorus
	Average break-even price	Average break-even price
	Dollars	
All	**31**	**268**
No livestock – Less than 100 acres of cropland	20	179
No livestock – 100 or more acres of cropland	13	126
Some livestock but not likely to be confined	44	375
Small animal feeding operations (AFOs)	15	135
Without excess	12	101
With excess	67	213
Medium AFOs	27	242
Without excess	9	82
With excess	49	305
Large AFOs	29	242
Without excess	9	74
With excess	46	285

[1] Break-even price is the price at which the farm would participate in nutrient trading, meaning the price at which the value of credits sold is equal to the cost of producing the credits. For example, the average small AFO with excess onfarm nitrogen would need to see a credit price of $67 in order to participate in nutrient trading.

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

Conclusions

Land-applied manure contributes 17 percent of nitrogen and 26 percent of phosphorus loadings to the Bay. AFOs constitute only 15 percent of Chesapeake Bay farms and control only 30 percent of the Bay's cropland and pastureland, but they control 63 percent of manure-applied acres. Targeting AFOs to improve manure management would likely provide larger per-farm reductions in nutrient loadings from manure than targeting crop- or pasture-based operations.

To even more efficiently target policy dollars, regulators may consider focusing on AFOs that generate more manure nutrients than they can assimilate onfarm. Forty-five percent of recoverable manure nitrogen and 60 percent of recoverable manure phosphorus produced on farms in the Chesapeake Bay watershed cannot be assimilated on the farms on which it is produced. Over a quarter of AFOs produce excess nitrogen, while nearly half generate excess phosphorus. Ninety percent of the excess is generated at medium and large AFOs, and these operations are more likely than small AFOs to have no crop or pasture acreage on which to apply manure.

Prior efforts to mitigate nutrient runoff from manure have not generated the sufficient reduction in aggregate; hence, alternative or more intense policy actions are required if the TMDL is to be met. Nutrient trading is a market-based method proposed in the Chesapeake Bay TMDL to mitigate nutrient runoff, but there is little consideration for the potential barriers of including AFOs in trading. Federal CWA CAFO rules interact with the structure of a Chesapeake Bay nutrient trading scheme in a complex manner, potentially raising the costs to confined livestock operations of program participation. Because nutrient trading requires abiding by existing regulations before entering trading, potentially regulated livestock operations may face added costs related to satisfying CAFO requirements before generating credits. Part of satisfying baseline requirements may be shipping excess manure off-farm, entailing a cost the crop farmers ordinarily would not have. Programs outside of nutrient trading, particularly those that purchase manure for a positive price, could help make nutrient trading more attractive for livestock producers.

Beyond tangible costs, such operations may avoid participation in a nutrient trading program based on fears of regulatory scrutiny. These fears may be at least partially alleviated by having the trading authority enlist the help of an entity that is trusted by farmers. Accessing already embedded relationships with farmers can facilitate trust in a voluntary framework such as nutrient trading.

Beyond differences in baseline requirements, credit generation based on reductions in nutrients to cropland may have different costs depending on whether the producer generates manure or not. For producers only applying fertilizer, reduction in nutrient applications entails cost savings by purchasing less fertilizer. For producers that cover their crop nutrient needs predominantly with manure, reduction in nutrient applications requires shipping manure off-farm, an added cost.

These complications 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.

AFOs that generate more onfarm manure nutrients than they can assimilate on crops or pastureland are much less likely to participate in nutrient trading via reductions in land application of nutrients. This is largely because they have less cropland, and therefore can generate fewer credits from applying less manure nitrogen. To increase the likelihood of such producers' participation in nutrient trading based on land application of nutrients to cropland, policymakers could alter certain trading rules, or set the TMDL cap to be more stringent, thereby inducing higher priced credits. Trading could be structured to allow credits to be generated from shipping excess manure off farm, although further monitoring or rules would be required to avoid incentives at odds with overall discharge reductions. Policy programs outside of trading that create demand for poultry litter or livestock manure could also aid in encouraging farms with onfarm excess nutrients to participate in trading.

This report only modeled nutrient credit generation via reductions to cropland in order to compare trading participation by crop versus livestock producers. We did not explore other methods of nutrient credit generation that could be accomplished only by livestock producers, such as shipping all manure off-farm (even beyond what is required for a NMP or 15-percent reduction in nutrient applications to cropland). Such analysis is saved for future work, but would inform relative costs of livestock- versus crop-producer participation in nutrient trading.

References

Abdalla, C.W., T. Borisova, D.D. Parker, and K. Saacke Blunk. 2007. "Water quality trading and agriculture: Recognizing the challenges and policy issues ahead," *Choices* 22(2): 117-124.

Bongard, P. 2012. *Nitrogen fertilizer research for corn on irrigated soils*, University of Minnesota Extension, Dakota County Agriculture Production and Water Quality Program fact sheet. https://www.co.dakota.mn.us/Environment/WaterQuality/Agriculture/Documents/FertilizerResearchFactSheet.pdf

Branosky, E., C. Jones, and M. Selman. 2011. *Comparison Tables of State Nutrient Trading Programs in the Chesapeake Bay Watershed.* World Resources Institute Fact Sheet. http://www.wri.org/publication/comparison-tables-state-nutrient-trading-programs-chesapeake-bay-watershed

Breetz, H., K. Fisher-Vanden, H. Jacobs, and C. Schary. 2010. "Trust and Communication: Mechanisms for Increasing Farmers' Participation in Water Quality Trading," *Land Economics* 4: 44-62.

Centner, T.J. 2003. "Regulating concentrated animal feeding operations to enhance the environment." *Environmental Science and Policy* 6: 433-440.

Center, T.J. 2004. "Developing institutions to encourage the use of animal wastes as production inputs," *Agriculture and Human Values* 21: 367-375.

Centner, T.J., and G.L. Newton. 2011. "Reducing CAFO permitting requirements," *Journal of Animal Science* 89:4364-4369. https://www.animalsciencepublications.org/publications/jas/pdfs/89/12/4364

Chesapeake Bay Commission. 2004. Cost-Effective Strategies for the Bay: 6 Smart Investments for Nutrient and Sediment Reduction. http://www.chesbay.us/Publications/cost%20effective.pdf

Chesapeake Bay Commission. 2012. Nutrient Credit Trading for the Chesapeake Bay: An Economic Study. RTI International, Research Triangle Park, NC. http://www.chesbay.us/Publications/nutrient-trading-2012.pdf

Chesapeake Bay Foundation. 2004. *Manure's Impact on Rivers, Streams, and the Chesapeake Bay: Keeping Manure Out of the Water.* http://www.cbf.org/document.doc?id=137

Chesapeake Bay Foundation. 2001. *Chesapeake Bay Program Nutrient Trading Fundamental Principles and Guidelines.* EPA 903-B-01-001, CBP/TRS 254/01.

Chesapeake Bay Foundation. 2013. The Chesapeake Bay Program 2013. In accordance with Clean Water Act § 117. Submitted by U.S. Environmental Protection Agency on Behalf of Chesapeake Bay Program, Annapolis, MD. http://www.chesapeakebay.net/documents/cbp_rtc_2013.pdf.

Code of Federal Regulations. 2003. "National Pollutant Discharge Elimination System Permit Regulation and Effluent Limitation Guidelines and Standards for Concentrated Animal Feeding Operations (CAFOs)," Title 40, Parts 9, 122, 123, and 412, p. 7176-7274.

Commonwealth of Pennsylvania. 2006. NPDES General Permit for CAFO Operations (PAG-12). Bureau of Watershed Management. 3910-PM-WM0034. http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-54998/3910-PM-WM0034.doc

Commonwealth of Virginia. 2010. Chesapeake Bay TMDL Phase I Watershed Implementation Plan. November 29. http://www.deq.virginia.gov/Portals/0/DEQ/Water/TMDL/Baywip/vatmdlwip-phase1.pdf

Copeland, C. 2006. *Animal waste and water quality: EPA regulation of concentrated animal feeding operations (CAFOs),* CRS Report for Congress Order Code RL31851.

Copeland, C. 2011. *Animal waste and water quality: EPA's response to the Waterkeeper Alliance Court Decision on Regulation of CAFOs*, CRS Report for Congress. RL33565.

Delaware's Chesapeake Interagency Workgroup. 2010. Delaware's Phase I Chesapeake Bay Watershed Implementation Plan. Nov. 29. http://www.dnrec.delaware.gov/swc/wa/Documents/ChesapeakePhaseIWIP/DE_PHASE1_WIP_11292010.pdf

Federal Register. July 20, 2012. "National Pollutant Discharge Elimination System Permit Regulation for Concentrated Animal Feeding Operations: Removal of Vacated Elements in Response to 2011 Court Decision," Vol. 77, p. 44494.

Goldberg D. 2007. "Liquid manure spills in Skaneateles—Officials say leak kills some fish, but poses no threat to Owasco, Skaneateles Lakes." *The Post-Standard*. Syracuse, NY. July 12. P. B1.

Gollehon, N., and M. Caswell. 2000. "Confined Animal Production Poses Manure Management Problems," USDA, Economic Research Service. *Agricultural Outlook*, September.

Guyer, P.Q., and D.D. Duey. 1974. *G74-99 Estimating Corn and Sorghum Silage Value. Historical Materials from University of Nebraska-Lincoln Extension*, Paper 352. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1349&context=extensionhist

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

Kellogg, R.L., D.C. Moffitt, and N. Gollehon. Forthcoming. *Estimates of Recoverable and Non-Recoverable Manure Nutrients Based on the Census of Agriculture,* USDA, Natural Resources Conservation Service.

Key, N., W.D. McBride, M. Ribaudo, and S. Sneeringer. 2011. *Trends and Developments in Hog Manure Management: 1998-2009*, USDA, Economic Research Service, EIB-81. September. http://www.ers.usda.gov/publications/eib-economic-information-bulletin/eib81

King, D. 2005. "Crunch time for water quality trading," *Choices* 20(1): 71-76.

King, D.M., and P.J. Kuch. 2003. "Will nutrient credit trading ever work? An assessment of supply and demand problems and institutional obstacles," *Environmental Law Institute* 33: 10352-10368.

Kobell, R. 2013. “West Virginia poultry farmer sues EPA to clarify CAFO regulations,” *Bay Journal*. Oct. 10. http://www.bayjournal.com/article/west_virginia_poultry_farmer_sues_epa_to_clarify_cafo_regulations

Latane, A., and K. Stephenson. 2011. Agricultural nutrient nonpoint source credits: A comparison of state crediting procedures, selected paper for presentation at the Southern Agricultural Economics Association Annual Meetings, Corpus Christi, TX. Feb. 5-8. http://ageconsearch.umn.edu/bitstream/98823/2/VA%20PA%20NPS%20credit%20comparison.pdf

Lyons E.R. 2014. “EPA’s authority gone awry: The flawed CAFO reporting rule,” *Vermont Journal of Environmental Law* 15: 599-628.

MacDonald, J.M., M.O. Ribaudo, M.J. Livingston, J. Beckman, and W. Huang. 2009. *Manure Use for Fertilizer and for Energy: Report to Congress.* USDA, Economic Research Service. June. http://www.ers.usda.gov/publications/ap-administrative-publication/ap-037.aspx

Maryland Department of the Environment. 2009. General Discharge Permit for Animal Feeding Operations. Maryland Permit No. 09AF. NPDES Permit No. MDG01. Land Management Administration, Baltimore, MD. http://www.mde.state.md.us/assets/document/waste/AFO_General_Permit.pdf

Maryland Department of the Environment. 2010a. Maryland’s Phase I Watershed Implementation Plan for the Chesapeake Bay Watershed. http://www.mde.state.md.us/programs/Water/TMDL/TMDLHome/Pages/Final_Bay_WIP_2010.aspx

Maryland Department of the Environment. 2010b. Title 26 Department of the Environment. Subtitle 08 Water. 26.08.03.09. Land Management Administration. Solid Waste Program, Baltimore, MD. http://www.dsd.state.md.us/comar/getfile.aspx?file=26.08.03.09.htm

Morgan, C., and A. Woolverton. 2008. “Water Quality Trading in the United States: Trading Programs and One-Time Offset Agreements,” *Water Policy* 10(1): 73-93.

National Association of State Departments of Agriculture. 2000. State Environmental Laws Affecting West Virginia Agriculture. A Project of the National Association of State Departments of Agriculture Research Foundation. http://www.nasda.org/nasda/nasda/foundation/state/WestVirginia.pdf

National Pork Producers Council. 2011. *NPPC Scored CAFO Suit Victory Over EPA,* Press Release. March 15. http://nppc.org/nppc-scores-cafo-suit-victory-over-epa

Natural Resources Defense Council. 1998. *America’s Animal Factories: How States Fail to Prevent Pollution from Livestock Waste.* http://www.nrdc.org/water/pollution/factor/aafinx.asp

Newburn, D., and R. Woodward. 2012. “An Ex-Post Evaluation of Ohio’s Great Miami Water Quality Trading Program, *Journal of the American Water Resources Association* 48(1):156-169.

New York State Department of Environmental Conservation. 2010. Final Phase I Nutrient and Sediment Water Quality Improvement and Protection Plan. http://www.dec.ny.gov/docs/water_pdf/finalphaseiwip.pdf

Pennsylvania Department of Environmental Protection. 2010. Pennsylvania Chesapeake Watershed Implementation Plan. http://www.epa.gov/reg3wapd/pdf/pdf_chesbay/PADRAFTWIP9-1-2010.pdf

Pennsylvania Department of Environmental Protection. 2015. Program requirements. https://www.portal.state.pa.us/portal/server.pt/community/nutrient_trading/21451/program_requirements/1548035

Pennsylvania State University Agronomy Guide. 2011-2012. Nitrogen Fertilizers. http://extension.psu.edu/agronomy-guide/cm/sec2/sec28

Perez, M. 2011. "Regulating Farmers: Lessons Learned from the Delmarva Peninsula," *Choices* 26(3). http://www.choicesmagazine.org/choices-magazine/theme-articles/innovating-policy-for-chesapeake-bay-restoration/regulating-farmers-lessons-learned-from-the-delmarva-peninsula

Ribaudo, M., J. Delgado, L. Hansen, M. Livingston, R. Mosheim, and J. Williamson. 2011. *Nitrogen in Agricultural Systems: Implications for Conservation Policy,* ERR-127, USDA, Economic Research Service.

Ribaudo, M., N. Gollehon, M. Aillery, J. Kaplan, R. Johansson, J. Agapoff, L. Christensen, V. Breneman, and M. Peters. 2003. *Manure Management for Water Quality: Costs to Animal Feeding Operations of Applying Manure Nutrients to Land,* AER-824, USDA, Economic Research Service.

Ribaudo, M.O., and J. Gottlieb. 2011. "Point-nonpoint trading—can it work?" *Journal of the American Water Resources Association* 47(1):5-14.

Ribaudo, M., J. Savage, and M. Aillery. 2014. *An Economic Assessment of Policy Options to Reduce Agricultural Pollutants in the Chesapeake Bay,* ERR-166, USDA, Economic Research Service.

Sheriff, G. 2005. "Efficient Waste? Why Farmers Over-Apply Nutrients and the Implications for Policy Design," *Applied Economic Perspectives and Policy* 27(94): 542-557.

Sneeringer, S. 2013. "Differences between livestock and crop producers' participation in nutrient trading." *Applied Economic Perspectives and Policy* 35(2): 296-321.

Snyder, C. 2011. "Calculating corn silage value," *Ag Weekly.* March 8. http://www.agweekly.com/articles/2011/03/08/commodities/dairy/dairy79.txt.

Staples, C.R. 1995. *Bermudagrass: Growing, storing, and feeding for dairy animals*, University of Florida IFAS Extension Publication CIR1140. http://edis.ifas.ufl.edu/pdffiles/DS/DS13100.pdf

Talberth, J., C. Jones, M. Perez, M. Selman, and E. Branosky. 2010a. *How Baywide Nutrient Trading Could Benefit Virginia Farms,* Working Paper, World Resources Institute, Washington, DC. http://www.wri.org/publication/how-baywide-nutrient-trading-could-benefit-virginia-farms

Talberth, J., C. Jones, M. Perez, M. Selman, and E. Branosky. 2010b. *How Baywide Nutrient Trading Could Benefit Maryland Farms,* Working Paper, World Resources Institute, Washington, DC. http://www.wri.org/publication/how-baywide-nutrient-trading-could-benefit-maryland-farms

U.S. Department of Agriculture, Economic Research Service. 2012. Fertilizer use and price data product, Table 7 – Average U.S. farm prices of selected fertilizers 1960-2013. http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx

U.S. Department of Agriculture, National Agricultural Statistics Service. 2014. *Crop Values 2013 Summary*. http://usda.mannlib.cornell.edu/usda/nass/CropValuSu//2010s/2014/CropValuSu-02-14-2014.pdf

U.S. Department of Agriculture, National Agricultural Statistics Service. 2009. *Crop Values 2008 Summary*. http://usda.mannlib.cornell.edu/usda/nass/CropValuSu//2000s/2009/CropValuSu-02-13-2009.pdf

U.S. Department of Agriculture, National Agricultural Statistics Service. 2011. *Crop Values 2010 Summary*. http://usda.mannlib.cornell.edu/usda/nass/CropValuSu//2010s/2011/CropValuSu-02-16-2011.pdf

U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS). 2011. *Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Chesapeake Bay Region*. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcsdev11_023934.pdf

U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS). 2013. *Impacts of Conservation Adoption on Cultivated Acres of Cropland in the Chesapeake Bay Region, 2003-06 to 2011.* Conservation Effects Assessment Project (CEAP). http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/ceap/?cid=stelprdb1240074

U.S. Environmental Protection Agency. 2002. *Concentrated Animal Feeding Operation: Clean Water Act Requirements*, EPA-833-F-02-009. https://www3.epa.gov/npdes/pubs/cafo_brochure_dairy.pdf

U.S. Environmental Protection Agency. 2003. *NPDES Permit Writers' Guidance Manual and Example NPDES Permit for Concentrated Animal Feeding Operations,* Office of Water, Office of Wastewater Management, Water Permits Division. EPA-833-B-04-001.

U.S. Environmental Protection Agency. 2009a. *The Next Generation of Tools and Actions to Restore Water Quality in the Chesapeake Bay: A Revised Report Fulfilling Section 202a of Executive Order 13508.*

U.S. Environmental Protection Agency. 2009b. *Water Quality Trading Toolkit for Permit Writers,* Office of Wastewater Management Water Permits Division. EPA 8330R-07-004.

U.S. Environmental Protection Agency. 2010. *Chesapeake Bay Total Maximum Daily Load (TMDL)*, Executive Summary. http://www.epa.gov/reg3wapd/pdf/pdf_chesbay/FinalBayTMDL/BayTMDLExecutiveSummaryFINAL122910_final.pdf

U.S. Environmental Protection Agency. 2013. *NPDES CAFO Rule Implementation Status*, National Summary. http://water.epa.gov/polwaste/npdes/afo/upload/tracksum-endyear2013.pdf

U.S. Environmental Protection Agency. 2014a. Chesapeake Bay Program, personal communication from Jeff Sweeney, Integrated Analysis Coordinator, March.

U.S. Environmental Protection Agency. 2014b. *Reducing Acid Rain*. http://www.epa.gov/air/caa/peg/acidrain.html

U.S. Environmental Protection Agency. 2015. *Acid Rain Program*. http://www.epa.gov/airmarkets/programs/arp/index.html

U.S. Government Accountability Office. 2003. *Livestock Agriculture: Increased EPA Oversight Will Improve Environmental Program for Concentrated Animal Feeding Operations,* Report to the Ranking Member, Committee on Agriculture, Nutrition and Forestry, U.S. Senate, GAO-03-285. http://www.gao.gov/new.items/d03285.pdf

U.S. Government Accountability Office. 2008. *Concentrated Animal Feeding Operations: EPA Needs More Information and a Clearly Defined Strategy to Protect Air and Water Quality from Pollutants of Concern,* Report to Congressional Requesters, GAO-08-994.

Virginia Administrative Code. 9 VAC 25-192-70. General Permit for Pollutant Management Activities for Animal Feeding Operations. http://lis.virginia.gov/cgi-bin/legp604.exe?000+reg+9VAC25-192-70

Virginia Department of Environmental Quality. Undated. *Trading Nutrient Reductions from Nonpoint Source Best Management Practices in the Chesapeake Bay Watershed: Guidance for Agricultural Landowners and Your Potential Trading Partners*. http://www.deq.virginia.gov/Portals/0/DEQ/Water/PollutionDischargeElimination/VANPSTradingManual_2-5-08.pdf

Virkler, S. 2005. “Massive manure spill taints river – Fish killed, water left undrinkable.” *Watertown Daily Times*. Aug. 15. P. D8.

Walker, S., and M. Selman. 2014. Addressing Risk and Uncertainty in Water Quality Trading Markets. World Resources Institute. Issue Brief. http://www.wri.org/sites/default/files/wri_issuebrief_uncertainty_3-9_final.pdf

Water Quality Goal Implementation Team. 2011. *Clarification on CAFO Loads and TMDL Allocations*. http://archive.chesapeakebay.net/pubs/calendar/47043_02-14-11_Handout_2_11160.pdf

West Virginia Department of Environmental Protection. 2010. Concentrated Animal Feeding Operations (CAFO) Application, Division of Water and Waste Management. http://www.dep.wv.gov/WWE/permit/individual/Pages/default.aspx

West Virginia WIP Development Team. 2010. *West Virginia’s Chesapeake Bay TMDL Watershed Implementation Plan*. http://www.wvca.us/bay/files/bay_documents/208_WV_Final_WIP_I_Nov_29_2010.pdf

Wilson, I. 2008. “Manure storage: The center of controversy,” *The Frederick News-Post*. Feb. 2.