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Reducing Nutrient Pollution from Animal Agriculture Operations in Pennsylvania: Hope for the Chesapeake Bay

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Finding the ways that work

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Disclaimer:

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Honor Pledge:

On my honor as a student, I have neither given nor received aid on this assignment.

May 3, 2018

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GLOSSARY

Estuary	Where the tide meets one or more rivers to create a partially enclosed body of fresh- and saltwater.
Concentrated Animal Feedlot Operation (CAFO)	An animal agriculture operation with more than one million pounds of livestock and/or poultry or a CAO with over 300,000 pounds of livestock and/or poultry.
Concentrated Animal Operation (CAO)	An animal agriculture operation with more than 8,000 pounds of livestock and/or poultry and over 2,000 pounds of live animal weight per acre that manure can be applied to.
Nonpoint source	Pollution from widely distributed sources that are difficult to quantify.
Nutrient load	The quantity of nutrients in the water supply.
Point source	Pollution from a localized, stationary, and identifiable source.
Runoff	The water and the substances carried by the water drained from an area of land.
Watershed	An area of land from which all water drains to a common outlet.

ACRONYMS

AAO	Animal Agriculture Operation
BMP	Best Management Practice
CAFO	Concentrated Animal Feedlot Operation
CAO	Concentrated Animal Operation
EPA	Environmental Protection Agency
MMP	Manure Management Plan
NMP	Nutrient Management Plan
NPDES	National Pollutant Discharge Elimination System
PADEP	Pennsylvania Department of Environmental Protection
TMDL	Total Maximum Daily Load
VAO	Voluntary Agricultural Operation
WIP	Watershed Implementation Plan

EXECUTIVE SUMMARY

The Chesapeake Bay does not meet water quality standards set by the Clean Water Act. Poor water quality attributable to high nutrient concentrations costs the Bay billions of dollars in economic losses ("The Economic Importance of the Bay," 2017). **About 16 percent of the nitrogen and 12 percent of the phosphorus that enters the Bay every year originates on animal agriculture operations in Pennsylvania** (Russ et al., 2017). This year, Pennsylvania will develop Phase III of its strategy to reduce nutrient concentrations in the Bay. The Environmental Defense Fund seeks to focus their advocacy efforts on a particular policy that Pennsylvania should include in the Phase III strategy.

I review the current literature and present four policy options for addressing the problem. In Option 1, the state government does not include any new policies in the Phase III strategy and allows present trends to continue. In Option 2, the government revises and expands the existing Nutrient Management Plan program. These changes require best management practices that are cost-effective at the regional level and inclusion of 20,000 additional farms currently managed under a non-mandatory program. In Option 3, the government introduces a tax on nitrogen and uses the tax revenue to reimburse farmers for implementing best management practices. In Option 4, Pennsylvania hires additional employees to help farmers retire land and encourage various stakeholders to create or expand reimbursement programs for farmers that retire land.

I evaluate the options according to six criteria: (1) the percentage of nitrogen and phosphorus reduction goals that the option accomplishes, (2) the total cost of the option to the Pennsylvania government, (3) the cost of the option to the Pennsylvania government per pound of nitrogen pollution reduced, (4) the distribution of costs between farmers and the Pennsylvania government, (5) the longevity of the option, and (6) the political and administrative feasibility of the option. Based on these criteria, **I recommend that the Environmental Defense Fund advocate for Option 2: Revise and expand the Nutrient Management Plan program.** This program achieves nutrient reduction goals by the target date of 2025 at a reasonable cost to the government and farmers. This option will sustain low nutrient loads after 2025 and face limited political and administrative problems.

I recommend that the Environmental Defense Fund advocate for phased-in implementation of Option 2. Pennsylvania should implement the changes in two management regions per year, starting with the regions within the Chesapeake Bay Watershed. The government should adjust the program during implementation as needed. This analysis serves as a preliminary comparison of policy options. The government should conduct additional research on the selected option before moving forward with implementation.

PROBLEM CONTEXT

Problem Statement…………………………………………………………….....

Sixteen percent of the nitrogen (41 million pounds) and 12 percent of the phosphorus (2 million pounds) entering the Chesapeake Bay every year originates from animal agriculture operations in Pennsylvania (Russ et al., 2017).

Background……………………………………………………………………

The Chesapeake Bay & Watershed

The Chesapeake Bay is the third largest estuary in the world. Estuaries are unique ecosystems that provide nesting and feeding grounds for many species. Estuaries also filter pollutants, sequester carbon, and mitigate flooding. The Chesapeake Bay supports vibrant industries, including ecotourism, fishing, and real estate ("Facts & Figures," 2017). Ecotourism and fishing alone contribute $5 billion and $3.5 billion, respectively, to the Bay economy ("The Economic Importance of the Bay," 2017).

The water that flows into the Chesapeake Bay drains from the 64,000-acre Chesapeake Bay Watershed ("Facts & Figures," 2017). Only Maryland, Delaware, Virginia, and Washington D.C. contain Bay shoreline, but rivers from Pennsylvania, New York, and West Virginia also feed into the Bay. The Susquehanna River, which originates in Pennsylvania, is the Bay's largest tributary. Over 18 million people populate the Watershed, and the population increases by almost two percent annually ("Facts & Figures," 2017).

Figure 1: Chesapeake Bay Watershed

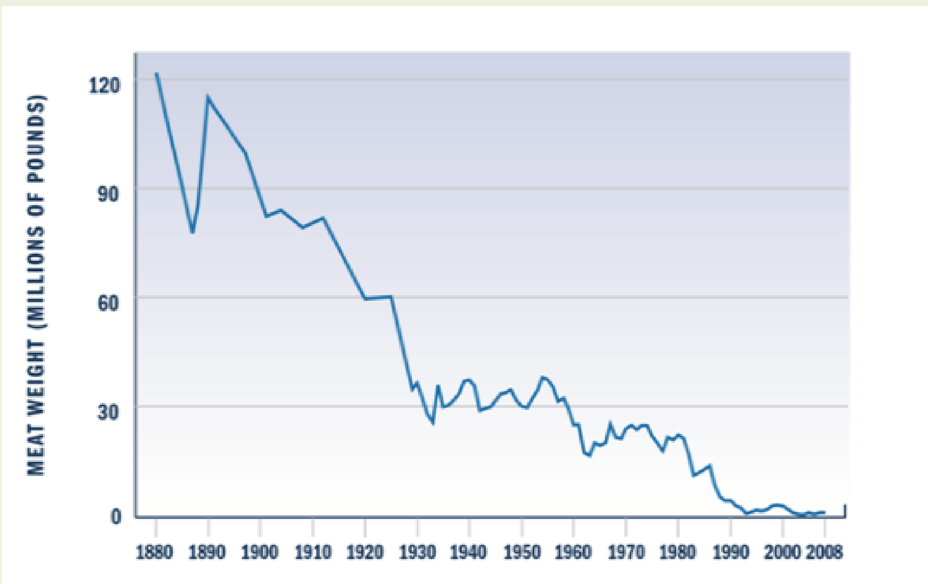
Source: United States Geological Survey

The Health of the Bay

Water quality in the Chesapeake Bay has become an increasing problem over the last 100 years. The steep decline in water quality observed over the last 50 years exceeds all previous declines since the 1600s ("USGS Fact Sheet FS-116-00," 2000). The Chesapeake Bay Foundation, a nonprofit organization that advocates for a healthy Bay, scores the Bay's overall health at 32 percent, where 100 percent represents a healthy Bay ("Nitrogen & Phosphorus," 2017).[1]

The Bay's poor water quality negatively affects the regional economy. Blue crab population declines have cost the region over $640 million; oyster losses (depicted in Figure 2) have cost $4 billion ("The Economic Importance of the Bay," 2017). Poor, Pessagno, and Paul (2007) found that housing prices near the shore dropped by between $1,086 and $17,642 for a one milligram per liter decrease in water quality.[2]

Figure 2: Oyster harvests in the Chesapeake Bay, 1880 to present



Source: NOAA Chesapeake Bay Office

Estimates for total economic gains from improving water quality are as high as $30 billion (Phillips & McGee, 2016). Commercial and recreational fisheries will gain between $8 and $85 million per year from improved water quality. Outdoor recreation benefits range from $105 to $280 million per year (Massey et al., 2017). Estimated benefits to real estate vary

[1] The Chesapeake Bay Foundation estimates that a "healthy" Bay mirrors Bay conditions in 1600.
[2] Results presented in this sentence are specific to the study area but other authors have produced similar results in other regions (Cho, Roberts, & Kim, 2011; Wolf & Klaiber, 2017; Wolf, Georgic, & Klaiber, 2017).

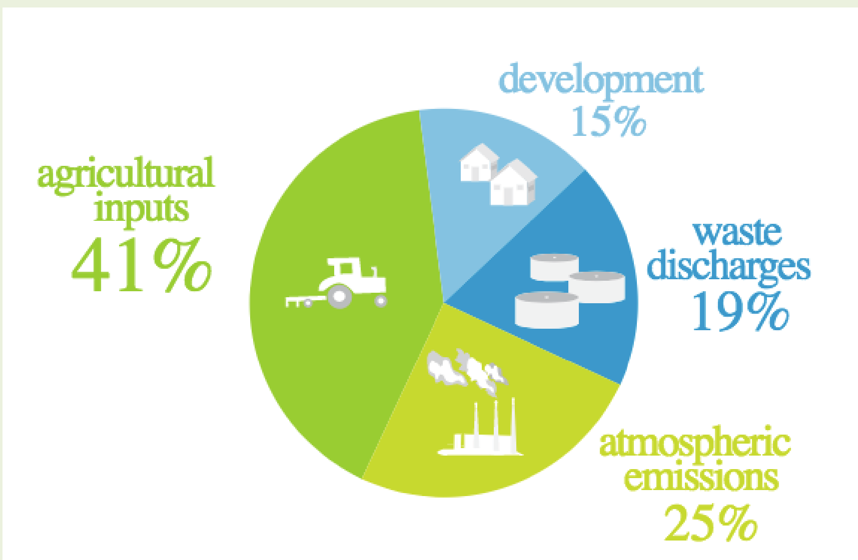
considerably, but the Environmental Protection Agency (EPA) indicated that homes in close proximity to the shoreline will enjoy 25 percent increases in value if water quality improves (Walsh et al., 2017; “The Economic Importance of the Bay,” 2017).

Causes of Pollution: Animal Agriculture in Pennsylvania

Scientists assess water quality in the Bay based on nutrient and sediment concentrations. In this analysis I focus on nutrients, which endanger the environment in high concentrations by (1) creating harmful algal blooms that lead to decreased aquatic life, and (2) limiting the Bay’s ability to filter harmful pollutants out of the water (“The ABCs of HABs,” n.d.).

Agriculture is by far the largest source of nutrients to the Bay, accounting for 40 and 50 percent of the Bay’s annual nitrogen and phosphorus loads, respectively (see Figure 3)(“2017 and 2025 Watershed Implementation Plans (WIPs),” n.d.). Due to the high intensity of agriculture in Pennsylvania, the state is responsible for nearly half of the annual nitrogen and a quarter of the annual phosphorus entering the Bay from agriculture. While crop farms apply nutrients as fertilizer, animal agriculture operations (AAOs) produce large quantities of nitrogen and phosphorus in the form of manure. In the most heavily farmed counties in Pennsylvania, 61 percent of the nitrogen pollution and 76 percent of the phosphorus pollution comes from animal manure (Russ et al., 2017).

Figure 3: Sources of nitrogen to the Chesapeake Bay



Source: Chesapeake Bay Story

Animal production in Pennsylvania has increased dramatically since the 1980s, especially on concentrated animal operations (CAOs). In 2012, there were 62,200 AAOs in Pennsylvania, up 50 percent from 2007 (Pennsylvania Department of Agriculture, National Agriculture Statistics Service, 2012). Over half of the state's AAOs fall within the Chesapeake Bay Watershed. There are 323 concentrated animal feedlot operations (CAFOs), and 100 million animals in the Pennsylvania portion of the Bay Watershed (U.S. Environmental Protection Agency, 2015; Russ et al., 2017). Manure from poultry, hogs, and livestock runs off into streams and ends up in the Chesapeake Bay if not stored or processed properly. The sheer volume of manure produced on AAOs and the high costs of adopting best practices for manure management makes limiting pollution difficult for farmers (Ribaudo, Savage, & Aillery, 2014).

Existing Policy

The Pennsylvania Department of Environmental Protection (PADEP) regulates nutrient loads on AAOs through Manure Management Plans (MMPs) and Nutrient Management Plans (NMPs). I outline the different AAOs and their associated policy requirements in Table 1.

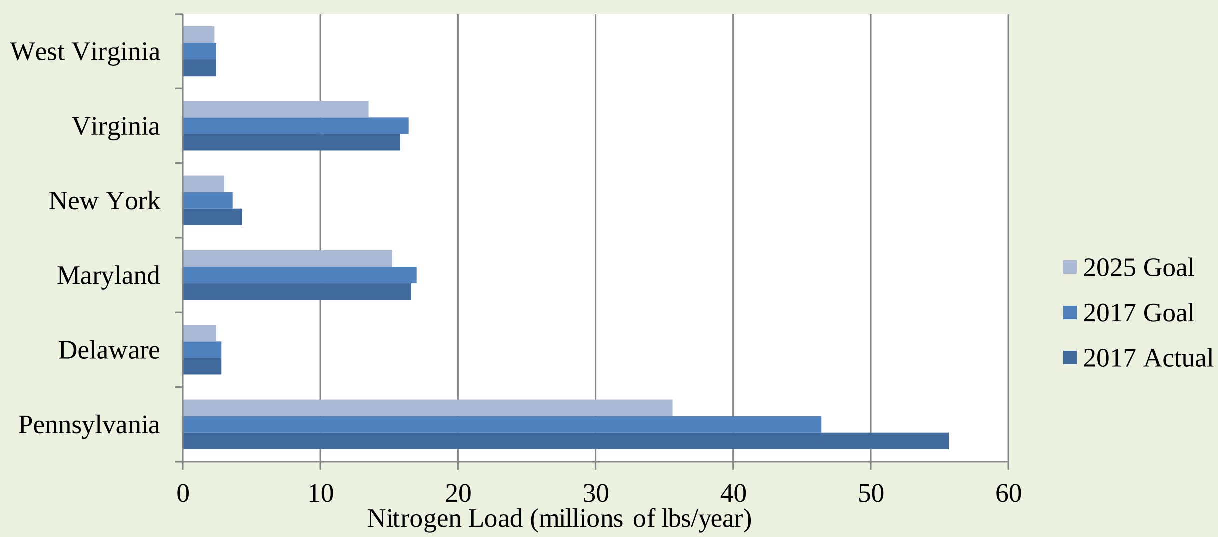
Table 1: Types of Animal Agriculture Operations and Associated Policies in Pennsylvania

Operation	Definition	Management Plan	Government Approval
CAFO: Concentrated Animal Feedlot Operation	Over 1 million pounds of livestock/poultry OR CAO with over 300,000 pounds of livestock/poultry	Nutrient Management Plan National Pollutant Discharge Elimination System Permit	Pennsylvania Department of Environmental Protection
CAO: Concentrated Animal Operation	Over 8,000 pounds of livestock/poultry AND Over 2,000 pounds of live animal weight per acre that manure can be applied to	Nutrient Management Plan	County Conservation District OR State Conservation Commission
VAO: Voluntary Agricultural Operation	Non-CAO or CAFO operations that opt into the NMP program	Nutrient Management Plan	County Conservation District OR State Conservation Commission (To receive benefits)
Neither CAO nor CAFO	Less than 8,000 pounds of livestock/poultry	Manure Management Plan	None

Source: U.S. Environmental Protection Agency, 2015

In 2010, the EPA introduced the Chesapeake Bay Total Maximum Daily Load (TMDL) program to restore the health of the Bay by reducing nutrient loads entering the Bay from the six states in the watershed. Nutrient load refers to the quantity of nutrients (nitrogen and phosphorus) in the water supply. The program requires each state to develop and implement strategies to achieve the TMDL goals, called Watershed Implementation Plans (WIPs). The TMDL program also determined that states should achieve 60 percent of the progress towards their goals by 2017 (“Chesapeake Bay TMDL,” 2017). Pennsylvania is the only state that has not met its goals for phosphorus reduction. While other states are close to their nitrogen goals, Pennsylvania is 36 percent behind its goal (Russ et al., 2017). Figure 4 illustrates Pennsylvania’s large contribution to nutrient pollution and the state’s failure to meet goals that other states have.

Figure 4: Progress toward agriculture TMDL goals by state



Source: Chesapeake Progress

States develop and implement WIPs in three phases. Phase III of Pennsylvania’s WIP will be developed in 2018 and implemented from 2019 to 2025. The Environmental Defense Fund (EDF) seeks to advocate for policies that PADEP should include in Phase III of the WIP to help Pennsylvania achieve TMDL goals. In this report, I analyze the pros and cons of existing policy and the relevant literature to evaluate policy options for nutrient reduction from AAOs in Pennsylvania. I propose four policies that EDF could advocate for, and I evaluate the options according to six criteria. Based on my analysis, I select one option for EDF to advocate for implementation of via Pennsylvania’s Phase III WIP.

LITERATURE REVIEW

There are two main approaches to nutrient management policy: standards and incentives. Standards policies use legal power to set requirements that farmers must meet. Incentives policies use economic tools to encourage farmers to meet standards voluntarily. Policies can also be either performance-based or design-based. Performance-based policies directly mandate or create incentives for nutrient load reductions. Design-based policies indirectly affect nutrient loads by requiring specific strategies that result in reduced nutrient loads (Ribaudo, Savage, & Aillery, 2014).

Standards

The Nutrient Management Plan (NMP) program, which became the dominant pathway to nutrient reduction in the early 2000s, is an example of a standards policy. NMPs include restrictions on nutrient application rates and required implementation of other best management practices (BMPs). When created and implemented correctly, NMPs effectively reduce nutrient use. Beegle et al. (2000) determined that matching crop needs to nutrient application rates minimizes nutrient runoff and maximizes crop yield. Shepard (2005) confirmed in a field study that farmers with NMPs applied 26 percent less nitrogen and 28 percent less phosphorus to their crops, on average, than farmers without NMPs. More recently, Wang and Baerenklau (2015) used a modeling approach to find that implementation of NMPs decreased nitrogen runoff from farms by 84 percent. These studies are limited by their small sample area and simulation assumptions. While it is clear that NMPs reduce nutrient use, determining the effect of NMPs on water quality is more complicated. Liu et al. (2017) suggested in a review article that many authors have found that NMPs reduce nutrient pollution. Due to low data availability and the complex nature of the geoecological factors at play, the magnitude of the relationship between NMP implementation and nutrient loads remain largely uncertain.

Some researchers have argued that NMPs may not be effective policy instruments due to low implementation rates. High implementation costs and low enforcement deters farmers from complying. Farmers are usually unwilling to admit noncompliance to government sources, but several anonymous surveys provide rough estimates of implementation rates. In a 2011 Watershed-wide survey, only nine percent of farmers applying manure to their crops adopted NMPs. In Maryland, around two-thirds of farmers implemented NMPs in recent years, so adoption may vary significantly between states ("Nutrient Management & the Chesapeake Bay," 2015). Maryland inspects nearly 17 percent of farms every year, as opposed to Pennsylvania's two percent (Maryland Department of Agriculture, 2015; U.S. Environmental Protection Agency, 2015). Osmund et al. (2015) and Cela et al. (2016) corroborated low implementation rates in other locations. Government involvement and one-on-one or small-group training opportunities can increase NMP adoption rates (Ulrich-Schad et al., 2017; Osmond et al., 2015; Cela et al., 2016). Thus, government action could improve the efficacy of NMPs in Pennsylvania.

Incentives

Proposals for incentives programs include water quality trading, taxing nutrient pollution, and offering subsidies for BMP implementation. A water quality trading system sets a cap on total nutrient loads for the state and assigns farmers a share of the total nutrient load. The system then allows for trading of nutrient units amongst farmers. Pennsylvania already runs a nutrient trading program. Water quality trading is economically efficient in theory, but the program excludes small farmers and requires farmers to achieve a base level of water quality to participate. These barriers to entry prevent the program from growing and limit cost savings to farmers. Van Houtven et al. (2012) estimated that expanding water quality trading to basin and Watershed scales would produce cost savings of 44 and 49 percent, respectively, compared to the current policy. More recently, Stephenson et al. (2017) found that transaction costs associated with trades can be so large that farmers are better off not trading. Shortle et al. (2016) also contested the success of trading, suggesting that the delay in BMP implementation and resulting water quality changes further complicates monitoring and enforcement. I do not consider water quality trading as a policy option in this analysis because current research is inconclusive regarding changes that would be critical to improving the program, such as pricing and enforcement for small farms.

Placing a tax on nutrient loads creates incentives for farmers to adopt BMPs that limit nutrient pollution. The government could place a tax on a unit of nutrient pollution and use tax revenue to subsidize implementation of BMPs. Farmers would adopt BMPs until the implementation costs do not exceed the tax. BMP subsidies would help keep implementation costs down. Ribaudo, Savage, and Aillery (2014) estimated that tax rebate subsidies would cut implementation costs in half. Palm-Forster, Suter, and Messer (2016) and Wu and Tanaka (2005) found that a nutrient tax reduced pollution nearest to the social optimum, compared to other policy options. Offering subsidies resulted in the highest adoption rates of costly BMPs (Palm-Forster, Suter, & Messer, 2016). I interpret the results of these studies with caution because the authors used simulations and models applied to specific contexts, which limits the generalizability of the results.

Some authors have argued that enforcement complications could result in an inequitable and low-impact tax (Ribaudo, Savage, & Aillery, 2014; Choi & Feinerman, 1995). Monitoring stations do not currently exist at the necessary capacity to measure the effect that individual farms have on water quality (Ribaudo, Horan, & Smith, 1999). Existing systems in other locations rectify this problem by taxing nutrient application. Nutrient application and water quality do not have the same relationship across farms, however. Factors like soil quality and proximity to a water supply make some farmers more vulnerable to nutrient runoff than others (“Fact Sheet: Taxes on nutrients - nitrogen,” 2016). Other systems equally tax groups of farms known to contribute to the water quality at a particular monitor. Taxing groups of farms raises an equity issue but encourages farms to work together on the local scale to reduce pollution (Helming, 1999). Few researchers are investigating what a nutrient tax may look like in Pennsylvania or other states in the Bay Watershed, which limits predictions of additional complications that a nutrient tax could have in Pennsylvania.

Creating incentives for land retirement is another possible method for reducing nutrient runoff from AAOs. Land retirement is the practice of transitioning farmland out of production. Under the Farm Bill, the U.S. Department of Agriculture pays farmers annually according to the number of acres retired or transitioned to wetlands (Lambert & Sullivan, 2006). Shortle (2014) estimated that in Pennsylvania, the average marginal abatement cost of land retirement is almost 72 and 38 percent cheaper for nitrogen and phosphorus, respectively, than the average marginal abatement cost of other management practices. There are several reasons that these savings have not been realized. First, according to the Environmental Defense Fund (EDF), there are not enough federal funds to achieve the scale of land retirement necessary to achieve TMDL goals across the Watershed (Shier, 2017). Second, farmers find it difficult to comply with federal programs and laborious to meet their reporting requirements (Shier, 2017). As with NMPs, investment in training, education, and engagement between officials and farmers increases program enrollment (Ulrich-Schad et al., 2017; Osmond et al., 2015; Cela et al., 2016). Third, farmers differ in the payments that they are willing to accept for land retirement depending on their profits (Fraser & Stevens, 2008). Fraser and Stevens (2008) suggested that policies should set compensation rates that target farms with the greatest nutrient runoff. Finally, land retirement could lead to increased animal concentrations on AAOs, which would increase nutrient runoff (Marshall & Homans, 2006; Morris, 2014). Determining the extent of this concern in Pennsylvania requires more research.

Based on my review of the literature, enhancing NMPs, trading or taxing nutrients, and creating incentives for land retirement are the most popular and feasible options for reducing nutrient runoff from AAOs in Pennsylvania. Several of these options are thus be considered as policy options in this analysis.

EVALUATIVE CRITERIA

Achieves TMDL goals	*Percentage of the TMDL nitrogen and phosphorus goals likely to be completed by 2025*
Total cost	*Total cost to the Pennsylvania government*
Cost-effectiveness	*Total cost to the Pennsylvania government per pound of nitrogen pollution reduced*
Distribution of costs	*Ratio of dollars spent by farmers to dollars spent by the Pennsylvania government*
Longevity	*Ability of alternatives to remain effective after 2025*
Political and administrative feasibility	*Ability of the Pennsylvania government to adopt and implement the option*

I evaluate the policy options proposed according to six evaluative criteria. The criteria include both qualitative and quantitative measures. For the quantitative criteria, I adjust uncertain input data to project minimum, median, and maximum scenarios. I present the median scenario in the outcomes matrix on page 29 with the range depicted below. The range represents the values I project in the minimum and maximum scenarios. I select the criteria based on the priorities and values of the Environmental Defense Fund (EDF).

Achieves TMDL goals

The EPA determined that states should meet TMDL goals by 2025. Policy options should result in nutrient load reductions that meet or approach Pennsylvania's TMDL goals. Through this criterion I assess the degree to which options create futures in which Pennsylvania meets TMDL goals. I represent this criterion as a percentage of the TMDL nutrient reduction goal that this option is likely to complete by 2025. For example, an option could achieve 75 percent of the nutrient load reduction required by the TMDL program. I prefer options that achieve more progress toward TMDL goals over options that achieve less progress. I present this criterion in terms of nitrogen and phosphorus.

Total cost

Total cost represents the cost to the Pennsylvania government to implement the option. I include all costs that accrue between 2019, when the Phase III WIP takes action, and 2025, when the TMDL program sunsets. It is outside the scope of this analysis to consider the costs of options after 2025. I do not consider the cost to non-profits or third-party companies in this analysis because they are not legally required to act under the policy options. I also exclude costs to the federal government because the Pennsylvania government has limited control over federal spending. I calculate costs to farmers as part of the distribution of costs criterion (see Appendix). Costs to farmers can be determined by multiplying the total cost to the Pennsylvania government by the ratio of farmer cost to government cost.

Cost-effectiveness

The cost-effectiveness of each alternative measures the total cost of the alternative to the Pennsylvania government per pound of nitrogen pollution abated. I restrict this criterion to nitrogen for clarity. I assess cost-effectiveness through 2025, the next existing policy goal. Lower cost-effectiveness values reflect higher efficiency in this analysis.

Distribution of costs

Across the alternatives, different stakeholders bear the implementation costs. I use the distribution of costs criterion to measure the allocation of costs between the Pennsylvania government and farmers. I represent the distribution as dollars spent by farmers for every one dollar spent by the Pennsylvania government. I consider farmers here as a collective group. Average costs to individual farmers can be determined by dividing the cost to farmers by the number of farmers. I prefer options where farmers bear a lower proportion of the cost because farmers are less likely to comply if they cannot afford the policy.

Longevity

The TMDL program intends for states to remain at low nutrient pollution levels after 2025. I use the longevity criterion to qualitatively assess the likelihood that alternatives remain effective over the long-term. I use classifications of Low, Medium, and High to differentiate the expected longevity between alternatives. More information about the distinctions between these classifications can be found in the Appendix. I prefer alternatives with higher longevity over alternatives with lower longevity.

Political and administrative feasibility

Political and administrative feasibility qualitatively describes the likelihood that the Pennsylvania government approves and implements a given policy option. Political feasibility depends on expected political stances regarding the policy. Politically feasible options have enough support to be passed and approved by the legislature. Administrative feasibility depends on the capacity of PADEP to change rules and make the necessary adjustments to staffing, organization, and/or resource-use. Administratively feasible options can be implemented by PADEP without requiring major investments or changes to the agency. I determine options to have either Low, Medium, or High political and administrative feasibility, with highly feasible options being the most preferable. More information about the distinctions between these classifications can be found in the Appendix.

POLICY OPTIONS

Option 1	*Let present trends continue*
Option 2	*Revise and expand the Nutrient Management Plan program*
Option 3	*Implement a nutrient tax and use the revenues to subsidize best management practices*
Option 4	*Encourage and facilitate pathways for farmers to conserve land*

Option 1: Let present trends continue……………………………………………

In Option 1, EDF proposes no changes to Pennsylvania's Watershed Implementation Plan (WIP) for Phase III with regard to nutrient runoff from animal agriculture operations (AAOs). It is likely that other groups will advocate for policy changes, but I assume for the purposes of this analysis that unless EDF recommends a policy change to the government, there will be no major adjustments to the WIP. Without policy intervention, Pennsylvania will continue to fall behind the goals set by the EPA's Chesapeake Bay TMDL program ("Chesapeake Bay TMDL Fact Sheet," 2015). Both nitrogen and phosphorus levels in the Susquehanna River (through which most of the pollution from Pennsylvania enters the Bay) increased over the past year, and phosphorus levels have been increasing consistently since 1985 (Moyer & Blomquist, 2017). Additionally, the number of small farms is decreasing, while the number of large farms is increasing (Alter et al., 2017). Although large farms are better regulated, they produce more pollution (U.S. Environmental Protection Agency, 2015).

Researchers who created a simulation of the Bay with different policy interventions reported that without action, nutrient reduction goals will not be achieved by 2025. The health of the Bay will continue to decline thereafter ("About The Game," 2018). Still, Watershed residents could make some progress towards nutrient reduction independent of government action. For example, farms may elect to participate in the NMP program as Voluntary Agricultural Operations (VAOs) even if their size does not require them to participate. In 2015 there were more VAOs participating in the NMP program than farms required by law to participate (1,797 voluntary vs. 1,502 required) (U.S. Environmental Protection Agency, 2015). As the cost of sustainable technology decreases, a culture shift could create incentives for farmers to become VAOs, but there is no evidence of such a shift in Pennsylvania. The number of VAOs is currently decreasing because farmers prefer Manure Management Plans (MMPs), which cost less than NMPs to implement (Russ et al., 2017). Unless this trend reverses, it is unlikely that unsponsored farmer efforts will result in TMDL achievement in the short-term. Allowing present trends to continue protects Pennsylvania farmers and the Pennsylvania government from bearing the costs of improving water quality in the Bay, but the Bay stands to lose over $30 million per year if water quality does not improve (Phillips & McGee, 2016). The Bay may seem distant to Pennsylvania farmers, but farmers rely on local water for their livelihood. As pollution increases, farmers will notice increasing scarcity in water used for drinking and irrigation (Blankenship, 2017).

Option 2: Revise and expand the Nutrient Management Plan program………..

The NMP program in Pennsylvania suffers from outdated standards, incomplete coverage, and poor data collection (U.S. Environmental Protection Agency, 2015). In Option 2, I recommend that EDF propose (1) revising the NMP manual to incorporate regionally cost-effective best management practices (BMPs), (2) expanding the NMP program to include farms that are currently only required to produce MMPs, and (3) transitioning to electronic recordkeeping.

Pennsylvania NMP and MMP manuals recommend nutrient application rates that exceed those recommended by scientific research, leading to increased nutrient runoff (Russ et al., 2017). Revising and updating NMP requirements would produce more nutrient reduction at a lower cost. Kaufman et al. (2014) found that setting nutrient standards and selecting required BMPs on a local scale could cut costs for farmers in Pennsylvania by up to 73 percent. The government should provide grant money for studies to determine which BMPs are most cost-effective for each region of the state. The government should then revise NMP standards to incorporate these findings.

The state government should also expand the NMP program to include farms currently only regulated by the MMP program. NMPs only manage about half of the manure load in the state of Pennsylvania. Assuming that NMPs are equally effective on smaller farms, expanding the NMP program would help address the state's unmanaged manure load. This change would bring about 20,000 additional farms under the NMP program, increasing the size of the program by a factor of six. In order to accommodate the increased number of farms, the government should hire nine additional inspectors to meet the EPA's recommended 10 percent per year inspection rate (U.S. Environmental Protection Agency, 2015).

The above changes should be accompanied by a transition from paper records to electronic data management. According to an EPA report (2015), Pennsylvania's management of NMPs as paper files is cumbersome and leads to missing data and poor enforcement. Switching to an electronic system could allow for improved record-keeping and increased capacity for local and adaptive management. The Pennsylvania Department of Environmental Protection (PADEP) recently transitioned their segment of the National Pollutant Discharge Elimination System (NPDES) to electronic records ("NPDES Electronic Reporting Rule," 2013). The government should use this experience to guide the NMP program transition.

Option 2 would result in increased cost-effectiveness of the NMP program and increased management over nutrient loads from AAOs. Option 2 is more feasible than other options because it focuses on design rather than performance. Option 2 also builds upon an existing program rather than creating a new program. Enforcement costs would increase, however, and farmers may disapprove of increased regulation.

Option 3: Implement a nutrient tax and use the revenues to subsidize best management practices…………………………………………………………..

In Option 3, I recommend that EDF advocate for a nutrient tax. The state government should assign a tax to excess nutrient pollution and use the revenues of the tax to subsidize the implementation of BMPs via reimbursements to farmers. Option 3 builds upon market principles, as opposed to familiar but usually inefficient command and control models. According to economic principles, when there is a low level of uncertainty regarding supply and demand and the cost of the tax exceeds the cost of complying with nutrient standards, taxes are efficient in reducing nutrient loads to the desired level. Similarly, subsidies make farmers more likely to adopt BMPs (Palm-Forster, Suter, & Messer, 2016; McDowell et al., 2016).

The government should design the tax such that the tax rate drives farmers to implement BMPs that decrease nutrient loads to the TMDL goal. The government should also choose to tax either nitrogen or phosphorus for ease of implementation and monitoring. Nitrogen is more abundant, so a nitrogen tax would be less expensive than a phosphorus tax. EDF should recommend that the government place a price on nitrogen pollution rather than phosphorus pollution. Most of the BMPs implemented will have the dual benefit of reducing both nitrogen and phosphorus ("Chesapeake Bay Program Best Management Practices," n.d.).

Current water monitoring technology complicates setting a nutrient tax. The government only monitors large farms, or point sources, closely enough to tax their nutrient runoff levels. A tax on large farms would result in significant water quality improvements because large farms produce the most nutrient pollution. Still, options exist for creating a more widespread tax. The government could tax water quality on a local or regional level. Taxes could also be based on nutrient production or application rather than water quality. EDF should recommend that the government begin with a tax on the 3,299 farms regulated under the NMP program. If the tax program is successful with these farms, the government should consider expansion options. My analysis only includes the 3,299 NMP farms because the framework for monitoring nonpoint sources has not been developed.

A tax on nitrogen may be unpopular amongst farmers depending on the rates set. Farmers will protest if the government decides to implement the tax on a regional level. A tax on nutrient purchase or application would also be inequitable. Geoecological factors prevent a direct relationship between nutrient application and nutrient loads, so farmers could apply the same amount of nutrients yet differ greatly in their contribution to nutrient pollution. Still, this option provides subsidies for farmers to implement BMPs, while other policy options do not provide financial assistance. This policy may be difficult to implement based on the lack of data available regarding nutrient taxes and the relationship between BMPs and nutrient loads. Despite these drawbacks, the tax program facilitates adaptive management because it allows the government to easily monitor and adjust policy as new information becomes available. Option 3 also offers the potential for considerable nutrient reduction.

Option 4: Encourage and facilitate pathways for farmers to conserve land…...

For the last option, EDF should recommend that the Pennsylvania government focuses on encouraging land retirement. Through the U.S. Department of Agriculture's Conservation Reserve Program, farmers enter a 10 to 15 year contract with the federal government. Farmers transition land out of agricultural use and plant species indicated by the government in exchange for annual payments ("Conservation Reserve Program," n.d.). Similar programs exist through the state government and nonprofit organizations, though on a smaller scale. Land retirement is one of the most cost-effective means by which to reduce nutrient pollution. The authors of a modeling study found that including land retirement in Pennsylvania's TMDL strategy increased cost savings relative to the Phase II WIP by 38 percentage points (Kaufman, et al., 2014). Ulrich-Schad et al. (2017) found that farmers that received more attention from local officials were nearly twice as likely to implement BMPs as farmers that received less attention from officials. EDF should advocate for additional resources to educate farmers about land retirement and improved communications between the state government and land retirement partners.

Educating farmers about federal, state, and private land retirement programs and facilitating opportunities for farmers to gain access to these programs would allow for significant nutrient load reduction at low cost to the state. To implement this option, the state should hire at least one additional education staffer in each of the 25 state offices. These staffers should conduct educational programs and provide training resources for farmers on how to apply and report to federal or other land retirement programs. Resources may include holding workshops, visiting farmers, and creating regional collaboration groups. The state should also hire two additional communications professionals to communicate with land retirement partners. These employees should advocate for increased conservation program funding in the upcoming 2018 Farm Bill and develop relationships with corporate and nonprofit organizations offering funding for land retirement.

Option 4 is low-cost and has the potential be highly effective in reducing nutrient loads. Increased farmer access to resources will likely boost implementation of land retirement. Option 4 could be less sustainable than other options in long-term, however, because there is a limit to the land retirement that can occur in Pennsylvania under current land retirement programs.

EVALUATION OF POLICY OPTIONS

In this section I discuss the evaluation of each option under the selected criteria. Additional information detailing the process by which I project each outcome can be found in the Appendix. A summary of the evaluation can be found in Table 6, on page 29.

Option 1: Let present trends continue……………………………………………

Achieves TMDL goals | I assume that if the Pennsylvania government does not introduce any new policies in the state's Phase III Watershed Implementation Plan (WIP), nutrient reduction between 2018 and 2025 will occur at the same rate as nutrient reduction between 2009 and 2017. At that rate, Pennsylvania will only achieve 30 percent of the nitrogen reduction and 44 percent of the phosphorus reduction required to meet the TMDL goal (Author calculations, Appendix). Compared to the other options analyzed, this option produces the lowest reductions for both nutrients.

Total cost | Option 1 is the lowest cost option. Adding no additional policies to the WIP will not increase the cost of the WIP to the government. The cost of Phase III of the WIP may increase from the cost of Phase II due to external factors or pre-planned increases, but this criterion only measures cost increases due to additional policy interventions. Thus, the cost of Option 1 to the Pennsylvania government is $0 (Author calculations, Appendix).

Cost-effectiveness | The cost of Option 1 to the Pennsylvania government per pound of nitrogen reduced is $0 because the total cost of the option is $0 (Author calculations, Appendix).

Distribution of costs | Because Option 1 adds no additional policies to the Pennsylvania WIP, farmers spend $0 on Option 1 for every $1 that the government spends, where the government also spends $0 (Author calculations, Appendix).

Longevity | I expect that Option 1 will have low longevity. Without policy intervention, nutrient levels are likely to continue to exceed the goals set by the TMDL program. Many of the programs implemented in the WIP are temporary. Without the addition of long-term nutrient management policy, it is likely that nutrient levels will increase after the TMDL program phases out.

Political and administrative feasibility | Option 1 is highly politically and administratively feasible because it does not require any additional strain on the Pennsylvania government. There may be some pushback to inaction due to Pennsylvania's poor progress to date. Pushback is likely to come from environmentalists, whose opinions play a smaller role in politics than those of Pennsylvania's nearly 60,000 farmers ("State Agriculture Overview for Pennsylvania," 2017).

Table 2: Summary of Option 1 criteria evaluation

Criteria	Median Score	Score Range
Achieves TMDL goals	Nitrogen: 30% Phosphorus: 44%	N/A
Total cost	$0	N/A
Cost-effectiveness	$0	N/A
Distribution of costs	$0	N/A
Longevity	Low	N/A
Political and administrative feasibility	High	N/A

Source: Appendix

Option 2: Revise and expand the Nutrient Management Plan program……….

Achieves TMDL goals | I expect that Option 2 will achieve 69 and 152 percent of the TMDL nitrogen and phosphorus reduction targets, respectively (Author calculations, Appendix). Option 2 achieves 39 more percentage points of nitrogen reduction and 108 more percentage points of phosphorus reduction than Option 1. After Option 3, I expect this option to produce the most nutrient reduction. Although reduction varies based on farm-specific characteristics, there is sufficient literature on NMPs to enable reasonable confidence that this option will produce the expected nutrient reduction.

Total cost | The total cost of this option to the Pennsylvania government is $64 million (Author calculations, Appendix). Option 2 is more expensive than Options 1 and 4, but it is less expensive than Option 3. Investment in electronic recordkeeping accounts for most of the cost to the government. Wages for new inspectors also increase the cost, but improved enforcement is critical to nutrient reduction. The cost of Option 2 is only eight percent of the average amount spent by the Pennsylvania government on WIP programs over the last three years ("Funding," 2018).

Cost-effectiveness | For every pound of nitrogen reduced, Option 2 costs the Pennsylvania government about $4.60 (Author calculations, Appendix). As expected for a traditional command-and-control policy, Option 2 has relatively poor cost-effectiveness as compared to the other options. The expected range for the cost-effectiveness of Option 2 is relatively small, however, and the poor cost-effectiveness is a tradeoff for high confidence in nutrient reduction loads.

Distribution of costs | Option 2 is the most equitable in terms of cost distribution between farmers and the Pennsylvania government. For every dollar that the government spends, farmers will spend $1.40 (Author calculations, Appendix). Low costs for farmers improve the likelihood that farmers will implement the option and that they will stay in business. Low relative costs also improve relations between farmers and the government, which improves the political feasibility of the option.

Longevity | I expect that Option 2 will have medium longevity. NMPs require farmers to implement several BMPs and abide by specified nutrient application rates. As farmers implement these requirements, I project that nutrient loads will decrease significantly. However, unless PADEP establishes more strict standards for NMPs, nutrient reductions will eventually stagnate. Option 2 thus has the capability to produce nutrient reductions and maintain nutrient loads at the stagnated level, but Option 2 is unlikely to continue producing nutrient reductions of the same magnitude over the long-term.

Political and administrative feasibility | Option 2 has medium political and administrative feasibility. The NMP program already exists, so Option 2 does not require that the government design and implement a new program. The option will regulate about 20,000 farms that are currently unregulated, which may produce opposition from small farmers. Those farmers will likely be able to obtain grants from the EPA or PADEP to reduce their burden. I expect most farmers to be in favor of adjusting NMP requirements to reflect regionally cost-effective BMPs because it will reduce costs for farmers by about 73 percent (Kaufman et al., 2014).

Table 3: Summary of Option 2 criteria evaluation

Criteria	Median Score	Score Range
Achieves TMDL goals	Nitrogen: 69% Phosphorus: 152%	Nitrogen: 36-104% Phosphorus: 101-202%
Total cost	$64 million	$63 million - $65 million
Cost-effectiveness	$4.60	$3.10 - $8.70
Distribution of costs	$1.40	$1.20 - $1.90
Longevity	Medium	N/A
Political and administrative feasibility	Medium	N/A

Source: Appendix

Option 3: Implement a nutrient tax and use the revenues to subsidize best management practices…………………………………………………………..

Achieves TMDL goals | Option 3 produces the highest projected reductions in nitrogen and phosphorus, but these projections rely on a strict set of assumptions that may vary considerably from the reality in which the government would implement this option. Under the assumptions made, I project that Option 3 will produce 180 and 202 percent of TMDL nitrogen and phosphorus reductions, respectively (Author calculations, Appendix).

Total cost | I expect Option 3 to incur the highest government costs, at $80 million (Author calculations, Appendix). Despite technology improvements, it remains expensive to monitor nutrient loads at the individual farm level. Generalizing monitoring to a local or regional level reduces government costs, but this strategy produces equity problems for agriculture operations of different sizes and with varying geoecological features. The cost of this option could be significantly adjusted based on the rate at which the government provides subsidy payments to farmers. Using the standard rate, in which the government pays for 75 percent of each BMP that a farmer implements, government costs accrue to $80 million.

Cost-effectiveness | Under Option 3, every pound of nitrogen reduced will cost the government $2.21 (Author calculations, Appendix). This option is more cost-effective than Option 2, but less cost-effective than Option 1 and Option 4. The cost-effectiveness projection is fairly uncertain due to the uncertainty in nutrient reduction and total cost projections for this option. Still, I would expect the cost-effectiveness of this option to be high under a variety of conditions due to the market-based nature of a tax.

Distribution of costs | For every dollar that the government spends on Option 3, I project that farmers will spend $2.72. In total, this option places a $218 million burden on farmers. The distribution of costs varies with the rate at which the government provides subsidy payments for each BMP that farmers implement. Farmers could pay between $0.46 and $231 per government dollar spent (Author calculations, Appendix). Due to farmer budgets, this option is only practical at a high government subsidy rate of at least 75 percent.

Longevity | Option 3 has the highest longevity relative to the other options. A nutrient tax and subsidy program allows for adaptive management. In order to project outcomes, I set the tax rate to accomplish TMDL goals. The tax rate could be adjusted by the government to achieve either increased or stagnate rates of nutrient reduction after Pennsylvania achieves TMDL goals. Adaptive management allows this policy to continue managing nutrient loads in the long-term.

Political and administrative feasibility | I expect that Option 3 will have low political and administrative feasibility. Designing and implementing a new tax will impose administrative strain on the Pennsylvania government. Pennsylvania farmers are likely to oppose a nutrient tax because it imposes additional costs on their operations. Monitored nutrient loads and actual nutrient loads from each farm are likely to differ significantly based on local factors, which will create an inequitable distribution of costs between farmers. Option 3 also requires that some programs already included in the WIP be removed because of conflicting incentives. For example, Pennsylvania already provides voluntary tax credits for farmers that implement BMPs. Option 3 would make this program repetitive; thus, the tax credit program should be cancelled if the government implements Option 3.

Table 4: Summary of Option 3 criteria evaluation

Criteria	Median Score	Score Range
Achieves TMDL goals	Nitrogen: 180% Phosphorus: 202%	Nitrogen: 179 – 190% Phosphorus: 193 – 204%
Total cost	$80 million	$0 - $439 million
Cost-effectiveness	$2.21	$0 - $11.55
Distribution of costs	$2.72	$0.46 - $231
Longevity	High	N/A
Political and administrative feasibility	Low	N/A

Source: Appendix

Option 4: Encourage and facilitate pathways for farmers to conserve land…...

Achieves TMDL goals | Option 4 will result in 62 percent of the TMDL nitrogen reduction and 117 percent of the TMDL phosphorus reduction (Author calculations, Appendix). This option will produce more nutrient reduction than Option 1 and less nutrient reduction than Options 2 and 3. The literature indicates that land retirement has the potential to produce large amounts of nutrient reduction, but the federal government caps the proportion of land that farmers can retire and receive benefits for. This program is voluntary, so although I expect this intervention to increase land retirement rates, some uncertainty remains with regard to the amount of nutrient reduction that will occur in practice. Based on my projections, nutrient reduction could be halved or doubled based on the adoption rate of land retirement.

Total cost | I expect that Option 4 will cost the Pennsylvania government $17 million (Author calculations, Appendix). These costs represent the wages of additional education and communications staff to help connect farmers with land retirement programs and inform them of land retirement benefits. Private sector organizations and the federal government will provide the land retirement payments to farmers, which enables this option to have the lowest state government costs relative to the other options.

Cost-effectiveness | Option 4 is the most cost-effective option for the Pennsylvania government. The government will pay $1.30 per pound of nitrogen reduced (Author calculations, Appendix). The cost-effectiveness of this option is high because of the low cost to the state government and the substantial nutrient load reductions that land retirement provides.

Distribution of costs | Despite low costs to the state government, Option 4 is costly to farmers. For every dollar that the government spends on Option 4, farmers will spend $8,150 (Author calculations, Appendix). This distribution makes Option 4 inequitable and the most costly option to farmers overall. Farmer costs are high because, on average, government payments are not enough to account for the capital cost of retiring land and the opportunity cost of not producing profits from the retired acres.

Longevity | I expect Option 4 to have medium longevity. Similar to Option 2, Option 4 will produce a set amount of nutrient reduction based on the amount of land retired by farmers. Nutrient loads will remain low into the foreseeable future, assuming that the land remains retired from agriculture. Option 4 will not produce increasing nutrient reduction rates over time unless the federal government adjusts their incentives program.

Political and administrative feasibility | Option 4 has high political and administrative feasibility compared to Options 2 and 3. This option is low-cost for the Pennsylvania government and it requires few administrative adjustments, with the exception of a few new hires to existing departments. I expect the take-up rate to be low due to the high cost to farmers. As a result, there may be farmer resistance to putting money toward this option. The investment is still relatively small compared to the other options and could even help some small farmers make money from their land. This option also does not require any changes to the regulatory or legislative code of Pennsylvania.

Table 5: Summary of Option 4 criteria evaluation

Criteria	Median Score	Score Range
Achieves TMDL goals	Nitrogen: 62% Phosphorus: 117%	Nitrogen: 25 – 124% Phosphorus: 47 – 235%
Total cost	$17 million	$8 million - $29 million
Cost-effectiveness	$1.30	$1.20 - $1.50
Distribution of costs	$8,150	$5,370 - $9,090
Longevity	Medium	N/A
Political and administrative feasibility	High	N/A

Source: Appendix

Table 6: Outcomes matrix

Option	Achieves TMDL goals		Cost			Longevity	Political and Administrative Feasibility
	Nitrogen	*Phosphorus*	*Total Cost*	*Cost-Effectiveness*	*Distribution of Costs*		
Option 1: Let present trends continue	30%	44%	$0	$0	$0	Low	High
Option 2: Revise and expand the NMP program	69% *(36-104%)*	152% *(101-202%)*	$64 million *($63 million-$65 million)*	$4.60 *($3.10-$8.70)*	$1.40 *($1.20-$1.90)*	Medium	Medium
Option 3: Implement a nutrient tax and subsidize BMPs	180% *(179-190%)*	202% *(193-204%)*	$80 million *($0-$439 million)*	$2.21 *($0-$11.55)*	$2.72 *($0.46-$231)*	High	Low
Option 4: Encourage and facilitate pathways for farmers to conserve land	62% *(25-124%)*	117% *(47-235%)*	$17 million *($8 million-$29 million)*	$1.30 *($1.20-$1.50)*	$8,150 *($5,370-$9,090)*	Medium	High

Source: Appendix

CONCLUSION

Recommendation……………………………………………………………………………………

I recommend that the Environmental Defense Fund (EDF) advocate for Option 2: revise and expand the Nutrient Management Plan (NMP) program. Option 2 will achieve significant progress toward Pennsylvania's TMDL goals at a reasonably low cost to farmers and the government. Option 2 does not rank the highest in terms of nutrient reduction, but I have higher confidence in the projected nutrient reduction for Option 2 than for Options 3 and 4. Based on the values of EDF, I prefer certainty over high potential nutrient gains.

Option 2 is the median option with regard to total cost, at $64 million. Expanding the NMP program will be a large investment for the Pennsylvania government, but the EPA has been pressuring Pennsylvania to update the program for two years. The Phase III Watershed Implementation Plan (WIP) is an ideal venue for the government to disclose its plans to improve the NMP program because the state will receive media attention and meaningful feedback from stakeholders in the WIP development process. The Pennsylvania government may also have an opportunity to receive grant money from the EPA. The cost-effectiveness of Option 2 is low, at $4.60, but Option 2 provides the most equitable distribution of costs between farmers and the government. I prefer increased equity over increased cost-effectiveness. If costs to farmers are too high, farmers may not be able to afford their farms. Farm failure would harm the Pennsylvania economy and the livelihoods of many long-time residents in central Pennsylvania.

Compared to the other options, Option 2 is the median with regard to both longevity and political and administrative feasibility. Nutrient loads will decrease for the first several years after farmers implement NMPs and then stagnate. If the government desires different stagnate levels in the future, making adjustments to the policy will be relatively slow because updates to the manual require scientific research and communication with thousands of farmers. Still, the policy can be updated to reflect future goals.

The moderate feasibility of Option 2 helps cancel out some of the option's disadvantages with regard to adaptive management. Additions to the WIP must be enacted quickly in order to make progress toward the 2025 nutrient reduction goals, so it is key that Option 2 does not require major administrative changes for the Pennsylvania Department of Environmental Protection (PADEP). It will take time for new farms to implement NMPs, enforcement to increase, and the electronic recordkeeping system to be installed and updated. Still, this option will likely produce results more quickly than Option 3 would because it does not require PADEP to create an entirely new program.

EDF should advocate that the Pennsylvania government revise and expand the nutrient management program because this option provides the most verified progress toward TMDL goals while remaining affordable and feasible for all parties. Low nutrient reduction potential disqualifies Option 1. High uncertainty and high total costs disqualify Option 3, while high costs to farmers disqualify Option 4. Based on the priorities of EDF and the Pennsylvania government, Option 2 is the best option to advocate for this year.

Caveats

This analysis serves only as a preliminary endorsement for Option 2. I conducted the analysis with the best data available to a non-government party. EDF should work with the Pennsylvania government to produce more accurate estimates of nutrient reduction and cost. It was not within the scope of this analysis to consider interaction effects of this policy with every other policy that may be included in the Phase III WIP for Pennsylvania. Before implementing this option with the Phase III WIP, the Pennsylvania government should review potential interactions with any other new policies.

The existing NMP program has been criticized for low implementation rates, which brings forth concerns that the projected nutrient reductions will not be realized if implementation rates continue to be low. The EPA states that enforcement increases implementation rates, so I expect that this effect will occur in Pennsylvania under Option 2 (U.S. Environmental Protection Agency, 2015). Implementation and enforcement efforts should be concentrated in the Chesapeake Bay Watershed region of the state in the short-term, to maximize the benefits of the policy to the Chesapeake Bay TMDL Program. Still, it is important to note that uncertainty remains regarding the effectiveness of the proposed policy. Additional caveats can be found in the methodology, described in the Appendix.

Implementation……………………………………………………………………………

EDF should recommend that the Pennsylvania government implement an expanded and revised NMP program by working collaboratively with stakeholders. PADEP should immediately allocate and announce research grants for studies on cost-effective BMPs by farm characteristics. I estimate that these grants should provide about $1,500 per study, with one or two studies in each of the six management regions. These grants should be awarded and negotiated as quickly as possible. PADEP's Grants Center should advertise, select researchers, and track progress for the grants.

PADEP should also introduce their intention to make changes to the NMP program in a press release. They should then hold town hall meetings in each of the six regions to answer questions and listen to feedback from attending stakeholders. EDF should offer to help publicize these meetings. PADEP should use Phase III WIP planning meetings to introduce the new policy and gather feedback. Following the meetings, PADEP should draft adjustments to the current program and submit them for public comment. EDF should attempt to maintain consistent communication during this phase to act as resource for PADEP. EDF should supply data and scientific research to PADEP whenever possible.

Upon receiving comments and making the relevant changes, PADEP should publish the rule adjustments and include the changes in the Phase III WIP. Because of the scale of the changes, PADEP should phase in the new policy by region. PADEP should aim to implement the policy in two new regions per year, beginning with the North-central and South-central offices, which have the most land in the Chesapeake Bay Watershed. Phasing in the policy regionally will provide time for PADEP to hire new inspectors, train farmers and new employees to use the online recordkeeping system, and rewrite NMP standards. PADEP should also seek to accept continuous feedback during the phase-in periods such that each year the program can be improved based on results.

EDF should seek to help solicit feedback from farmers and other stakeholders during the phase-in periods. EDF should also lead public education and engagement efforts to the extent that resources allow. Farmers may be more likely to provide honest feedback to a third party than to a government official. Because this policy will expand the NMP program to include six times more farms than it currently does, the government is likely to be constrained in terms of finances, staffers, inspections, and recordkeeping. PADEP may be hard-pressed to educate farmers about the new policies. Thus, EDF should fill this gap to ensure that policies are implemented correctly and that farmers avoid noncompliance penalties.

In 2022, one year after the policy has been implemented in all regions, the Pennsylvania government should produce a report on the progress of the policy and important lessons learned. EDF should encourage the government to frame this report in the context of the state's other Chesapeake Bay TMDL progress reports to determine whether the NMP program is helping Pennsylvania achieve state goals. At this point, the government should make necessary adjustments to keep the state on track.

Additional Considerations…..

In this analysis, I prefer Option 2 over the other options, but EDF could advocate for multiple options. Option 2 and Option 4 would both further the goals of EDF and they do not create conflicting incentives for farmers. Additionally, Option 4 is relatively inexpensive for the government to implement, at $17 million. If the government adopts both Option 2 and Option 4, the education staffers hired under Option 4 should run education programs about NMP compliance as well. Using these employees for both policies saves money and likely increases the implementation rate of NMPs as well as land retirement. I do not recommend that EDF advocate for Option 3 this year. The technology to make a nutrient tax efficient does not yet exist. Option 3 would likely drain government finances and require several years of research and development. A nutrient tax may be a long-term solution to manage nutrient pollution, but it should not be included in the Phase III WIP even if the funds are available.

I do not assess every potential policy option for reducing nutrient pollution from animal agriculture operations (AAOs) in this analysis. I do, however, compare four of the most popular options among professionals in the field. If the Pennsylvania government does not choose to implement either Option 2 or Option 4, EDF should continue to research other policy options or collaborate with other interest groups to develop new policy options. I recommend that EDF turn to other states first for potential policies.

Pennsylvania is running out of time to achieve TMDL goals. Each year that pollutants pour into the Bay, the ecosystem and the economy suffer. EDF should advocate for implementation of a revised and expanded NMP program through the Phase III WIP. If possible, they should also advocate for inclusion of land retirement funding. EDF should work in partnership with the government to ensure the success of these programs through 2025. It is still possible for Pennsylvania to achieve their goals; a healthy Bay and thriving farms can coexist.

Source: Patrick Wolf, Repro.nl

APPENDIX: METHODOLOGY

In this section I describe the progress by which I evaluate each policy option according to the selected criteria. I distinguish quantitative and qualitative criteria and then describe the methodology by option because each option required a different process to project the outcomes. I reflect the results of the analysis in Table 6, on page 29.

Qualitative Criteria……………………………………………………………………………

The qualitative criteria I assess are longevity and political and administrative feasibility. In general, I use the current literature and professional judgement to determine whether each option should be considered low, medium, or high for each criterion. For both longevity and political and administrative feasibility, I prefer options that score high over options that score low.

Longevity

I consider options with low longevity to be unlikely to attain or sustain nutrient loads required by the TMDL program. I consider options with medium longevity to be likely to achieve and sustain TMDL load targets but unlikely to facilitate increased load reductions after 2025. I consider options with high longevity to be likely to achieve TMDL target loads and likely to continue achieving load reductions after 2025.

Option 1: Let present trends continue (LOW) | Option 1 has low longevity. Option 1 offers no additions to the current suite of policies in the Phase II Watershed Implementation Plan (WIP). The WIP is not currently on track to achieve 2025 goals. Therefore, this option is unlikely to achieve, let alone sustain, healthy nutrient loads. Most of the policies in the WIP will lose funding when the program ends in 2025. Loss of funding would prevent nutrient load reductions from increasing after 2025.

Caveats:

- The Phase III WIP has not yet been finalized, so there are no materials available to indicate other new policies that may be added to the WIP. Other options not advocated for by the Environmental Defense Fund (EDF) may enable Pennsylvania to attain and sustain TMDL targets. I make professional judgements with the assumption that no new policies would be added to the WIP.

Option 2: Revise and expand the NMP program (MEDIUM) | Option 2 has medium longevity. Option 2 alone would achieve around 69 percent of the TMDL nitrogen goal and 152 percent of the TMDL phosphorus goal. After adding the 30 percent of nitrogen reduction expected in Option 1, I expect Option 2 to achieve both the 2025 nitrogen and phosphorus target loads. Changes to the NMP program would become a permanent part of Pennsylvania agriculture policy, so I expect that nutrient loads would remain low even after the TMDL program loses funding in 2025. I do not expect Option 2 to sustain nutrient reduction rates after 2025. NMPs require farmers to implement BMPs, but the nature of each BMP is to reduce nutrient loads by some amount and then sustain loads at the lower amount. For example, building a fence to prevent livestock from defecating in streams reduces nutrient loads by the amount attributable to livestock defecating in streams. Nutrient loads would then remain at the lowered rate into the foreseeable future because there are no more cows defecating in streams.

Caveats:

- Nutrient reduction rates depend on the nature of the BMP implemented. Since all farms would not implement the same BMPs, this analysis serves as a generalization, rather than a characterization of every farm.
- I assume that changes to the NMP program would not cause farmers to make changes to the way that they manage their farms. If the changes result in unintended consequences, such as farmers acquiring more or less livestock, my analysis may not hold.
- There is limited information on the effective lifespan of BMPs. Some BMPs may sustain low nutrient loads for longer than other BMPs before they require repairs or additional investments. Because the information on which BMPs are most cost-effective for different farms is not available yet, there is no way to estimate the exact longevity of various NMPs.
- In reality, farmers would implement NMPs and their required BMPs at different rates. For this analysis, I assume that all farmers implement all required cost-effective BMPs in 2019. There are insufficient data on the factors affecting implementation rates to warrant more detailed estimates.

Option 3: Implement a nutrient tax and subsidize BMPs (HIGH) | Although there is considerable uncertainty associated with Option 3, I project that, barring technology barriers, Option 3 would achieve TMDL nutrient load targets by 2025. A nutrient tax would continue to exist as a state program after WIP funding ends in 2025. It is therefore likely that Option 3 would sustain low nutrient loads after 2025. Option 3 has high longevity because the tax enables policymakers to continue decreasing nutrient loads beyond 2025. If policymakers continue increasing the tax rate, farmers would continue implementing BMPs and nutrient reductions would continue. Current science does not indicate that nutrient reductions beyond TMDL targets are necessary. Although Option 3 could attain additional nutrient reductions, policymakers may not choose to increase tax rates.

Caveats:

- I assume that each additional BMP has the same effects on nutrient reduction as the first BMP implemented. In reality, there may be decreasing marginal benefits. There is no literature on this topic, so I do not attempt to estimate decreasing marginal benefits.
- Farmers have different budgets based on their incomes. Some farmers would be priced out of the market by a tax unless they receive additional government support. There is little information available on the distribution of farmer incomes in the state of Pennsylvania. It is outside the scope of this analysis to account for the effects that tax rate increases may have on different farmers and thus overall nutrient loads.

Option 4: Encourage and facilitate pathways for farmers to conserve land (MEDIUM) | Option 4 alone achieves 62 and 117 percent of the nitrogen and phosphorus TMDL goals, respectfully. Adding in the 30 percent nitrogen reduction and 44 percent phosphorus reduction achieved by allowing present trends to continue, this option nearly achieves the nitrogen goal and exceeds the phosphorus goal. The Farm Bill is the primary funding source for land retirement, so funding would not expire in 2025 with the TMDL program. Land retirement is an example of a BMP. Land retirement reduces nutrient loads by the amount of nutrients that the retired lands contributed. The retired lands cannot reduce nutrient loads any further over time; therefore, this option would not produce continually increasing nutrient reduction rates after 2025.

Caveats:

- Funding for this option depends on Farm Bill appropriations. I assume that the budget for land retirement remains the same, but it may change with the 2018 Farm Bill.
- I assume that the nutrient reduction benefits from land retirement are constant over time. In reality, nutrient runoff from the retired acres would decrease gradually and then level off. Still, this decrease is likely to have leveled off by 2025.

Political and administrative feasibility

I consider options with low political and administrative feasibility to be neither politically nor administratively likely. Options ranked as medium are either likely politically or administratively, but unlikely in the other category. I consider options with high political and administrative feasibility to be both politically and administratively likely.

Option 1: Let present trends continue (HIGH) | Option 1 does not require any additional strain on the Pennsylvania government, so it is administratively likely. Option 1 may receive political backlash against inaction, but this backlash will be from the minority of voters rather than the majority. I thus consider option to be politically likely as well because politicians do not have to justify any additional burdens on voters.

Caveats:

- I assume that Pennsylvania politicians are more concerned about the votes of farmers than the votes of environmentalists. I also assume that farmers prefer options that do not impose financial burdens on them. I justify these assumptions based on information collected by my client, EDF, in other environmental campaigns (Shier, 2017).

Option 2: Revise and expand the NMP program (MEDIUM) | Option 2 is unlikely politically but likely administratively. I expect that all farmers would oppose increased enforcement because more farms would be penalized for failing to implement NMPs. I also expect that the approximately 20,000 farmers that were not previously required to implement an NMP would oppose this option because it would impose additional costs of about $1,600 per year on them. According to 2015 EPA estimates, about 85 percent of these farmers are not managing their manure at all (U.S. Environmental Protection Agency, 2015). Option 2 is likely administratively because it does not require the Pennsylvania government to construct a new program. The regulatory, staff, and monitoring structures for this option already exist. Option 2 requires changes to the program but these changes would still be easier than creating a new program. I anticipate that transitioning from paper to electronic records would be the most difficult aspect of this option, but the Pennsylvania government recently transitioned the National Pollutant Discharge Elimination System (NPDES) from paper to electronic records, so the framework for that transition exists ("NPDES Electronic Reporting Rule," 2013).

Caveats:

- There is no up-to-date quantitative data available on NMP implementation rates in Pennsylvania. I assume that implementation is low based on past data and low enforcement rates.
- I assume that farmers oppose policies that impose additional costs on them. Some farmers may be in favor of environmental policies. Based on low implementation rates of NMPs and Manure Management Plans, I assume that financial concerns take priority over environmental concerns (U.S. Environmental Protection Agency, 2015).

Option 3: Implement a nutrient tax and subsidize BMPs (LOW) | I expect Option 3 to be both politically and administratively unlikely. As a general rule, taxes are politically unpopular. I expect that they would be particularly unpopular amongst farmers, who have relatively low incomes compared to other professions. The tax would be difficult to pass without improved technology. Farmers would argue that the government's lack of certainty in attributing nutrient loads to specific farms makes the policy unfair. Option 3 is administratively unlikely because taxes are complicated to design and implement. This option would require expensive monitoring technology, staffers to administer the tax and subsidies, and thorough economic analysis beyond the estimates presented in this report. The Pennsylvania government would need to invest $80 million in the policy. This cost is higher than any other option. The cost would strain the government because there is no clear funding source.

Caveats:

- There is high uncertainty in the cost estimates for this option (see the quantitative criteria section). If a more thorough analysis is conducted with better data, the results may reveal lower costs. Lower costs would increase the political and administrative feasibility of Option 3.

Option 4: Encourage and facilitate pathways for farmers to conserve land (HIGH) | Option 4 is likely politically and administratively. Based on research conducted by EDF, farmers are interested in federal land retirement programs, but they struggle to keep up with the administrative requirements. Option 4 would meet farmers' needs rather than impose additional constraints on them because land retirement would be voluntary. Farmers are therefore likely to support rather than oppose this policy. Political backlash from other parties would also be limited because of the option's low cost and deferment of responsibility to the federal government. Option 4 imposes limited administrative strain. The new staff hired via this option would join existing departments in existing facilities.

Caveats:

- I assume that there would be office space available for the new employees because information pertaining to office availability is not available.

Quantitative Criteria……………………………………………………………………………

The quantitative criteria I consider are to what extent the policy achieves TMDL nutrient reduction goals and the cost of the policy. I consider TMDL goals in terms of nitrogen and phosphorus. I consider cost in terms of total cost to the Pennsylvania government, cost-effectiveness with respect to nitrogen and the Pennsylvania government, and cost distribution between farmers and the Pennsylvania government. For cost criteria, I represent all final estimates in 2018 dollars and use a seven percent discount rate to discount future costs. I choose a seven percent discount rate because the EPA uses this rate.

Achieves TMDL goals

Option 1: Let present trends continue | I assume that no policy changes to the WIP would result in the same average rate of nitrogen reduction occurring between 2018 and 2025 as occurred between 2009 and 2017. Using the following formula, I determine the annual rate of nutrient reduction between 2009 and 2017:

$$Annual\ nutrient\ reduction\ (lbs) = \frac{Nutrient\ load_{2017} -\ Nutrient\ load_{2009}}{2017 - 2009}$$

I then determine the projected nutrient load in 2025 using the following formula:

$$Projected\ nutrient\ load_{2025} = Nutrient\ load_{2017} - (Annual\ nutrient\ reduction\ \times\ (2025 - 2018))$$

In order to determine the percent of the TMDL goal achieved, I use the following formula:

$$Percent\ of\ TMDL\ goal\ achieved = \frac{Nutrient\ load_{2017} -\ Projected\ nutrient\ load_{2025}}{Nutrient\ load_{2017} - TMDL\ goal} \times\ 100$$

I obtain all relevant data from Chesapeake Progress. Chesapeake Progress is a website produced by the Chesapeake Bay program. The website provides annual nitrogen and phosphorus loads and load targets. I use loads and load targets for the agriculture sector in Pennsylvania ("2017 and 2025 Watershed Implementation Plans (WIPs)," 2016). I do not conduct maximum or minimum estimates for Option 1 because there are no relevant conditions to vary.

Caveats:

- I assume that the average rate of nutrient reduction from 2018 to 2025 would be the same as it was from 2009 to 2017 if there are no additions to the WIP in Phase III. In reality, there are likely to be minor changes to the WIP even if the government does not introduce any major new policies. External factors such as the national economy and the weather may impact nutrient loads. For example, there is more runoff in especially raining years, which could skew the results to suggest that less reduction occurred in the rainy year.

Option 2: Revise and expand the NMP program | I conducted a literature review to determine the effect of NMP implementation on nutrient loads. The relationship between NMP implementation and nutrient loads depends on regional environmental factors and NMP requirements. I found that NMP implementation thus has a varying effect on nutrient loads. I select the median estimate for my projection. I use the minimum and maximum estimate for my sensitivity analysis. I first determine the projected nutrient load in 2025 using the following equation:

$$Projected\ nutrient\ load_{2025} = Nutrient\ load_{2017} - (Nutrient\ load_{2017}\ \times\ Nutrient\ reduction\ factor)$$

Where the Nutrient reduction factor is a percent of the nutrient load reduced represented as a decimal. I then determine the percent of the TMDL goal achieved using the following equation:

$$Percent\ of\ TMDL\ goal\ achieved = \frac{Nutrient\ load_{2017} - \ Projected\ nutrient\ load_{2025}}{Nutrient\ load_{2017} - TMDL\ goal} \times 100$$

I gathered my estimates for the nutrient reduction factor from Darby, Halteman, and Heleba (2015), Maringanti, Chaubey, and Popp (2009), Hall and Risser (2007), Rao et al. (2009), and the Pennsylvania government ("Appendix D: TMDL Methodology used in Pennsylvania," 2001). I use the following nutrient reduction factors:

Table 1: NMP nutrient reduction factors by scenario

Nutrient	Minimum	Median	Maximum
Nitrogen	0.13	0.25	0.375
Phosphorus	0.25	0.375	0.5

I use loads and load targets for the agriculture sector in Pennsylvania from Chesapeake Progress ("2017 and 2025 Watershed Implementation Plans (WIPs)," 2016).

Caveats:

- Chesapeake Progress only provides data for the agriculture sector as a whole. Results may have been different if data specific to animal agriculture operations was available.
- The values I use as approximations of the nutrient reduction factor are generalizations from the literature. Actual values differ greatly depending on geoecological factors.
- I assume that all farms would implement a NMP due to increased enforcement and improved recordkeeping. A lower implementation rate would decrease the TMDL progress achieved.

Option 3: Implement a nutrient tax and subsidize BMPs | In Option 3, each farmer would implement the number of BMPs such that the cost of implementing the BMPs and paying the nutrient tax is less than the cost of paying the nutrient tax without implementing BMPs. I describe the procedure for determining the number of BMPs farmers would implement in the total cost section. I use the following equation to estimate the projected nutrient load in 2025:

$$Projected\ nutrient\ load_{2025} = (1 - BMP\ reduction\ factor)^{n} \times Average\ nutrient\ load\ per\ farm \times Number\ of\ farms$$

Where *n* is the number of BMPs implemented and the BMP reduction factor is the percent of the nutrient load reduced by each BMP, represented as a decimal. I determine the BMP reduction factor by selecting the minimum, median, and maximum values from the state government's estimates of BMP reduction factors for the BMPs relevant to animal agriculture operations ("Chesapeake Bay Program Best Management Practices," n.d.). I use the following BMP reduction factors:

Table 2: BMP reduction factors by scenario

Nutrient	Minimum	Median	Maximum
Nitrogen	0.65	0.50	0.25
Phosphorus	0.50	0.375	0.15

I divide the agriculture nutrient load in 2017 by the number of farms implementing NMPs in 2015 to determine the average nutrient load per farm ("2017 and 2025 Watershed Implementation Plans (WIPs)," 2016; U.S. Environmental Protection Agency, 2015). I determine the percent of the TMDL goal achieved using the following equation:

$$Percent\ of\ TMDL\ goal\ achieved = \frac{Nutrient\ load_{2017} - \ Projected\ nutrient\ load_{2025}}{Nutrient\ load_{2017} - TMDL\ goal} \times\ 100$$

Caveats:

- Chesapeake Progress only provides data for the agriculture sector as a whole. Results may have been different if data specific to animal agriculture operations was available.
- The BMP reduction factor varies for each BMP. For each scenario (minimum, medium, maximum) that I calculate, I select an average BMP reduction factor. Future research should attempt to incorporate more precise BMP reduction factors in calculations.
- I assume that only larger farms with greater nutrient runoff would participate in the tax program for ease of monitoring. I use the number of farms required to submit NMPs to estimate the number of farms that would be involved in the tax program. The government may choose to increase or decrease the program based on monitoring capabilities.
- See the total cost section for additional caveats.

Option 4: Encourage and facilitate pathways for farmers to conserve land | The federal government pays farmers to retire up to 20 percent of their farmland. The state government and the private sector also reimburse farmers for land retirement, although on a smaller scale. In order to project nutrient loads in 2025, I estimate the percent of land that would be retired under Option 4 and the effect that land retirement would have on nutrient loads. I estimate the effect that land retirement would have on nutrient loads using a model built by Shortle et al. in 2013. The authors estimate that if farmers retired 25 percent of the farmland in Pennsylvania, about

24.8 million pounds of nitrogen and one million pounds of phosphorus would be reduced (Shortle et al., 2013). At this rate, each percentage point increase in land retirement would result in about a 990,000 pound reduction in nitrogen and a 56,000 pound reduction in phosphorus. I use professional judgement to estimate possible land retirement rates. I project the outcomes at five, 12.5, and 25 percent land retirement. I project 2025 nutrient loads according to the following equation:

$$Projected\ nutrient\ load_{2025} = Nutrient\ load_{2017} - \ (Percent\ reduction\ assumed\ \times\ R)$$

Where *R* is the pounds of nutrient reduced per percentage point increase in the rate of land retirement. I determine 2017 and 2025 animal agriculture nutrient loads from Chesapeake Progress ("2017 and 2025 Watershed Implementation Plans (WIPs)," 2016). I determine the percent of the TMDL goal achieved via the following equation:

$$Percent\ of\ TMDL\ goal\ achieved = \frac{Nutrient\ load_{2017} - \ Projected\ nutrient\ load_{2025}}{Nutrient\ load_{2017} - TMDL\ goal} \times 100$$

Caveats:

- Chesapeake Progress only provides data for the agriculture sector as a whole. Results may have been different if data specific to animal agriculture operations was available.
- The authors that designed the model I use to determine the relationship between land retirement and nutrient loads used the model to assess cap and trade policy. The authors subjected the model to conditions that do not reflect the conditions of a land retirement program in Pennsylvania. A specific model created for farms in Pennsylvania would improve the accuracy of the calculation.
- I employ professional judgement to determine the rates at which land retirement may occur. There is no data to suggest how farmers would respond to the resources that Option 4 would create. I use the sensitivity analysis to provide a wide range of land retirement possibilities.

Total cost (to the government)

Option 1: Let present trends continue | The total cost for Option 1 is $0 because there would be no changes to the Phase III WIP if EDF does not advocate for one. I assume that no other interest groups would advocate for additional policies.

Option 2: Revise and expand the NMP program | I determine the government cost of Option 2 by collecting the annual costs. Costs to the government of Option 2 are the following:

- Studies to determine regionally cost-effective BMPs,
- Wages for additional inspectors, and
- Electronic record-keeping.

I estimate that grants for cost-effective BMP studies would cost the government $1,500 for each of the six management regions. There is no data available to confirm this estimate, so I estimate the cost to vary from $500 to $3,000 per region. I incorporate this range into the minimum and maximum estimates displayed in Tables 2-6. The cost of the study grants is a one-time expense to the government, accrued in 2019.

I estimate annual wages for inspectors to range from $50,564 to $77,506, with a median of $64,035. I source these estimates from the Bureau of Labor Statistics' reports on wages for agricultural inspectors by state ("Occupational Employment and Wages, May 2016," 2016). I adjust the wages reported to 2018 dollars. I determine that the state should employ nine new inspectors in order to meet the 10 percent inspection rate recommended by the EPA. In a 2016 report, the Pennsylvania Department of Environmental Protection (PADEP) estimates that each employee inspects about 305 farms per year. At that rate, PADEP would need about 17 inspectors to inspect 5,360 farms each year (10 percent of the existing 3,360 farms plus the additional 20,000 farms that this program would expand to include). PADEP already employs six inspectors, so they need to hire 11 more ("A DEP Strategy to Enhance Pennsylvania's Chesapeake Bay Restoration Effort," 2016). However, I expect that the 20,000 farms entering the program would take less time to inspect because they are smaller. I therefore scale down the estimate to nine inspectors. The wages of the nine employees accrue to the government every year from 2019 to 2025. I discount the wages at a seven percent discount rate, consistent with the EPA. The total cost of inspector wages to the government ranges from $2.45 million to $3.76 million, with a median of $3.11 million.

I determine the cost of adopting electronic recordkeeping for the NMP program to be similar to the costs of adopting electronic recordkeeping for the National Pollutant Discharges Elimination System (NPDES) program. The state government reports that the adoption cost $12.65 million per year for the first four years and decrease by $2.9 million every year following. I adjust these costs to 2018 dollars and discounted at a seven percent discount rate. I only consider costs through 2025.

I sum the costs from the three categories described to obtain the total cost to the government. Costs range from $63 million to $65 million, with a median of $64 million.

Caveats:

- I found no information to estimate the cost of grants for BMP studies. I use professional judgement to make an educated guess at the costs. The government should determine more accurate costs. Adjustment of study costs will adjust the overall cost of the option.

- I only include wages in the cost of hiring additional inspectors. Benefits, training, and other employment costs may adjust the overall cost, and the government should consider these costs when determining how many inspectors to hire.
- I estimate that inspectors would be able to inspect smaller farms more quickly than larger farms. If this assumption does not hold true, the government would need to hire more than nine new inspectors.
- I assume the cost of adopting an electronic recordkeeping system to mirror the cost of this transition for the NPDES program. The programs include different numbers of facilities of different sizes and types. It is beyond the scope of this analysis to adjust the cost of the NPDES electronic system to the NMP electronic system. The lack of data available would hinder the applicability of such an analysis. If possible, the government should consider how the costs of an electronic system would differ for the NMP program from the NPDES program.

Option 3: Implement a nutrient tax and subsidize BMPs | I estimate only the cost for the government to implement a nitrogen tax because there is less data available on phosphorus loads A phosphorus tax would likely also be too expensive for farmers.

I first determine the average percent reduction of nitrogen needed per farm in order to achieve the 2025 TMDL goal. I calculate the reduction needed per farm according to the following equation:

$$N\ reduction\ per\ farm = \frac{N\ load_{2017} - N\ load_{2025}}{Number\ of\ farms}$$

Where *N* represents nitrogen. I estimate the number of farms involved in the program to be the same as the number of farms currently enrolled in the NMP program. For monitoring purposes, I expect only the larger farms to be involved in the tax program (U.S. Environmental Protection Agency, 2015).

I next project the current average nitrogen pollution per farm. I determine this number by dividing the nitrogen load in 2017 by the number of farms. I use the following equation to determine the average percent nitrogen reduction required by each farm, where the percent is represented as a decimal:

$$Percent\ N\ reduction\ per\ farm = \frac{N\ reduction\ per\ farm}{Average\ N\ pollution\ per\ farm}$$

I used the following equation to determine the number of BMPs necessary to achieve the required percent nitrogen reduction per farm:

$$Percent\ N\ reduction\ per\ farm = BMP\ reduction\ factor^{n}$$

Where *n* is the number of BMPs implemented and the BMP reduction factor is the percent of the nutrient load reduced by each BMP, represented as a decimal. I determine the BMP reduction factor by selecting the minimum, median, and maximum values from the state government's estimates of BMP reduction factors for the BMPs relevant to animal agriculture operations ("Chesapeake Bay Program Best Management Practices," n.d.). I use BMP reduction factors of 0.65, 0.5, and 0.25 for nitrogen. Solving the equation for n with each of these values results in 1, 1.5, and 4 BMPs implemented, respectively.

I next determine the tax price per pound of nitrogen using the following equation:

$$\begin{aligned}&(Average\ N\ pollution\ per\ farm)P\\&\qquad = ((1 - BMP\ reduction\ factor)^{n})(Average\ N\ pollution\ per\ farm)P\\&\qquad + (Farmer\ cost\ per\ BMP)n\end{aligned}$$

Where *n* is the number of BMPs implemented and P is the tax price per pound of nitrogen. I determine the farmer cost per BMP to be the percentage of the implementation cost per BMP that the government does not provide subsidies for. The average total cost of each BMP is $45,000. In existing repayment programs, the government reimburses farmers for 75 percent of the implementation cost (Lecker, 2016). I use 75 percent as the median subsidy rate and I use subsidy rates of 60 percent and 90 percent in the sensitivity analysis. Solving this equation results in an average tax price per pound of nitrogen of $1.55.

I now summarize the government costs of implementing this tax. Costs to the government of implementing the tax are as follows:

- Cost to pay BMP subsidies,
- Cost to administer the tax, and
- Cost to enforce the tax.

I determine the total cost to pay BMP subsidies by multiplying the government cost per BMP implemented by the number of BMPs implemented per farm and the total number of farms. This calculation yields an average cost of about $167 million. This cost only accrues in 2019 because each farmer only has to implement the BMPs once.

I determine the cost to administer the tax based on the cost of the Resources Management and Protection (REAP) program currently administered by PADEP. The REAP program is a tax credit program, so I assume the costs would be similar. In the 2017 Pennsylvania budget, the REAP program cost $100,000 and included 265 farms. I use the following equation to calculate the administrative costs of the nitrogen tax, assuming that the per farm costs are the same as the REAP program:

$$N\ tax\ administrative\ cost = \frac{REAP\ program\ cost}{Number\ of\ farms\ in\ REAP\ program} \times Number\ of\ farms\ in\ N\ tax$$

Where *N* represents nitrogen. I determine the administrative cost of the nitrogen tax to be about $1.2 million. I convert this cost to 2018 dollars and assume that it accrues annually to the government.

I assume the cost to enforce the tax is equivalent to the cost to monitor the nitrogen concentrations. According to Pellerin et al. (2016), each nutrient measurement costs the government around $4,400. I convert this cost to 2018 dollars and multiply it by the number of farms in the program to determine the annual cost to enforce the tax. I assume that this cost accrues annually through 2025.

To determine the total cost to the government of the tax, I sum the cost to pay BMP subsidies, the administrative cost, and the enforcement cost. The median sum comes to $244 million. Income that the government earns from tax payments offsets some of this cost. I use the equation below to calculate tax revenue:

$$Tax\ revenue = Farmer\ cost\ per\ BMP \times n \times Number\ of\ farms$$

Where *n* is the number of BMPs implemented per farm. I discount all values at a seven percent discount rate. I calculate the median tax revenue to be $164 million. The total cost is thus about $80 million after subtracting the tax revenue from the costs.

Caveats:

- Chesapeake Progress provides data only for the agriculture sector as a whole. Results may have been different if data specific to animal agriculture operations was available.
- I assume that only larger farms with greater nutrient runoff would participate in the tax program for ease of monitoring. I use the number of farms required to submit NMPs in 2015 to estimate the number of farms that would be involved in the tax program. The government may choose to increase or decrease the program based on monitoring capabilities.
- The BMP reduction factor varies for each BMP. For each scenario (minimum, medium, maximum) that I calculate, I select an average BMP reduction factor. Future research should attempt to incorporate more precise BMP reduction factors in calculations.
- I assume that the government would choose to provide subsidies to farmers at between 60 and 90 percent of the total cost of BMP implementation. The government may adjust these costs to account for other expenses or to increase aid to farmers.

- I assume that all farmers implement BMPs in the first year of the program. In reality, implementation would occur gradually; however, it is outside the scope of this analysis to approximate that process.
- I assume that all farms contribute the same to nutrient pollution. In reality, a farm's contribution to nutrient pollution depends on a variety of factors, including implementation of BMPs and geoecological factors. It is outside the scope of this analysis to narrow effects to the farm level. I instead use an average to generalize the effects across all farms.
- There is limited information available to approximate the monitoring costs of implementing a nitrogen tax. Further research may reveal that monitoring is more or less expensive that I assume. I also assume that monitoring would only take place once a year. The government may prefer to monitor the water supply more often to avoid anomalies that could misrepresent reality. More frequent measurements would increase the enforcement cost to the government.

Option 4: Encourage and facilitate pathways for farmers to conserve land | The cost to the government of Option 4 consists of the following costs:

- Wages for educators,
- Wages for communications staff, and
- Program costs.

I estimate wages for educators using data on Pennsylvania wages by profession from the Bureau of Labor Statistics ("Occupational Employment and Wages, May 2016," 2016). I use minimum, median, and maximum wages of $50,000, $75,000, and $100,000, respectively. I determine that the government should hire between one and two new educators per office to ensure adequate access of farmers to professionals across the state. To determine the total cost of educator wages, I multiply the annual educator wage by the number of educators per office and the number of offices. I represent these wages in 2018 dollars. I assume that the wages accrue every year through 2025, and I use a discount rate of seven percent.

I use information form the Bureau of Labor Statistics to estimate wages for communications staff as well. I use minimum, median, and maximum wages of $75,000, $100,000, and $125,000, respectively ("Occupational Employment and Wages, May 2016," 2016). I determine that the government should hire two new communications staff to coordinate with the federal government and other land retirement partners. I multiply the annual wage of a communications staffer by two and accrue this cost annually through 2025 to determine the cost of communications staffers. I represent wages in 2018 dollars and I use a discount rate of seven percent.

I estimate program costs based on grants that the government currently provides for regional initiatives ("Nonpoint Source Mini-Grant Projects," 2017). I project that programs would cost between $250 and $5,000 per region per year. I multiply the regional cost per year by six regions to determine the annual cost of programs. I assume that program costs accrue annually through 2025. I represent costs in 2018 dollars and I use a discount rate of seven percent.

The sum of wages for educators, wages for communications staff, and program costs is the total cost of Option 4. The cost of Option 4 ranges from $8 million to $29 million, with an average cost of $17 million.

Caveats:

- I assume that the federal government or other stakeholders cover the complete costs of payments to farmers for land retirement. Costs for the state will be higher if the state accepts some fraction of the cost.
- I use the available literature to estimate wages and program costs. Real wages may differ, and the government should adjust these numbers in the analysis accordingly.
- I only include wages in the cost of hiring additional employees. Benefits, training, and other employment costs may adjust the overall cost, and the government should consider these costs when determining how many employees to hire.

Cost-effectiveness

I present cost-effectiveness as the cost to the Pennsylvania government in dollars per pound of nitrogen reduced. I restrict this analysis to nitrogen because the cost-effectiveness for nitrogen and phosphorus vary considerably. Cost-effectiveness is clearer to consider in terms of one nutrient. I use the following equation to determine the cost-effectiveness of all options:

$$Cost - effectiveness = \frac{Total\ cost\ to\ the\ state\ government}{Total\ pounds\ of\ nutrients\ reduced}$$

Distribution of costs

I determine the distribution of costs as dollars spent by farmers for every one dollar spent by the Pennsylvania government. I use the following equation to determine the distribution of costs:

$$Distribution\ of\ costs = \frac{Total\ cost\ to\ farmers}{Total\ cost\ to\ the\ state\ government}$$

I use estimates for total cost to the state government described in the "Total cost" section above. I use total cost to farmers as described in the sections that follow.

Option 1: Let present trends continue | There are no additional costs to farmers in Option 1 because I assume that there are no additional programs that inflict costs upon farmers. The distribution of costs is $0.

Caveats:

- I assume that no other groups would advocate for new policies. It is likely that new policies would be added, but it is outside the scope of this analysis to project those policies.

Option 2: Revise and expand the NMP program | I estimate costs to farmers of implementing NMPs based on the work of Edmunds et al. (2003), who studied NMP implementation costs to farmers by region. Where regional costs are available, I use costs for the northeast region. According to Edmunds et al. (2003), costs to farmers include:

- Manure and wastewater handling and storage,
- NMP development,
- NMP compliance, and
- Recordkeeping.

I include capital cost investments for manure and wastewater handling and storage and NMP development as one-time costs in 2019. I include operations and maintenance costs for manure and wastewater handling and storage, NMP compliance, and recordkeeping as annual costs that accrue through 2025. I multiply all per farm costs by 20,000 to represent the number of farms projected to join the program. I represent all costs in 2018 dollars and use a discount rate of seven percent. I complete my sensitivity analysis using the cost ranges available in the Edmunds et al. paper. I source NMP development costs from a 2017 PADEP press release ("DEP to Cover Cost," 2017).

After summing the above costs, I multiply the total cost by 0.73 and subtract that number from the total cost to reflect the cost savings of cost-effective BMPs. I use 73 percent cost reduction because Kaufman et al. (2014) report 73 percent cost savings in a journal article about implementing cost-effective BMPs in Pennsylvania. This estimate is the best available. Total costs to farmers of Option 2 after cost savings range from $78 million to $123 million with an average cost of $88 million.

Caveats:

- I base my estimates off of the Edmunds et al. paper, which the authors published in 2003. This article is the best comprehensive source of NMP cost estimates, however, it is outdated. Costs may have changed since 2003 in response to technology, climate, and other factors.

- I only consider costs in terms of monetary costs. There are also opportunity costs and social costs that could be considered. It is outside the scope of this analysis to monetize those costs.

Option 3: Implement a nutrient tax and subsidize BMPs | I use the process described under total cost to determine the number of BMPs that each farm would implement and the tax rate that each farm would face. The BMPs that farmers implement reduce the tax that farmers pay such that the cost to implement the BMPs and the cost to pay the tax for the resulting reduced nutrient load is less than the cost to pay the tax for the non-reduced nutrient load. I represent that equation below:

$$\begin{aligned} Cost\ to\ farmers_{BMPs\ implemented} \\ &= ((1 - BMP\ reduction\ factor)^{n})(Average\ N\ pollution\ per\ farm)P \\ &+ (Farmer\ cost\ per\ BMP)n \end{aligned}$$

Where *n* is the number of BMPs implemented and *P* is the price of the nitrogen tax per pound of nitrogen. I calculate the farmer cost per BMP subtracting the government subsidy rate from one and multiplying that decimal by the average cost to implement a BMP ($45,000). I assume that the cost to farmers accrues annually. I represent the cost in 2018 dollars and use a seven percent discount rate. The median total cost to farmers is $216 million.

Caveats:

- I assume that all farmers would implement BMPs right away. In reality, this process would occur over time. There is no data available on how the process would play out. The government should seek to assess this component of the cost further to ensure financial stability for farmers over time.
- See the total cost section for addition caveats.
- I only consider costs in terms of monetary costs. There are also opportunity costs and social costs that could be considered. It is outside the scope of this analysis to monetize those costs.

Option 4: Encourage and facilitate pathways for farmers to conserve land | Total costs for farmers of Option 4 include:

- Cost to retire land and
- Income loss from retired acres.

I estimate the cost to retire land from a database of BMP costs reported by the Pennsylvania government (“Pennsylvania Default Costs- BMP Costs,” n.d.). I use the following equation to determine the annual cost to retire land for all farms:

$$
\begin{aligned}
&Cost\ to\ retire\ land \\
&= Per\ acre\ cost\ to\ retire\ land \\
&\times \frac{\big((Number\ of\ farms\ \times\ Average\ acres\ per\ farm) \times\ Percent\ land\ retired\big) - Acres\ already\ retired}{7\ years}
\end{aligned}
$$

I estimate the total number of farms and the average number of acres per farm from Pennsylvania overview of the 2017 Agriculture Census ("2017 State Agriculture Overview for Pennsylvania," 2017). I obtain the number of acres already retired from USDA reports on the Conservation Reserve Program, which pays farmers to retire land ("Conservation Reserve Program," 2017). I determine percent of land retired to be five, 12.5 and 25 for the minimum, median, and maximum cost scenarios based on professional judgement. I assume that the annual cost found above would accrue every year through 2025. I represent costs in 2018 dollars and use a discount rate of seven percent. I find the median cost to retire land to be \$819 million for all farms.

I also estimate the costs to farmers in terms of profit losses. In the equation above, the second line containing the fraction bar represents the annual number of acres transitioned to land retirement. I project profit losses per year using the following equation:

$$
\begin{aligned}
&Annual\ profit\ losses \\
&\qquad = \frac{Annual\ acres\ transitioned\ to\ land\ retirement}{Average\ acres\ per\ farm} \times Average\ farm\ net\ income\ \times\ (1 \\
&\qquad - Percent\ income\ lost\ from\ retired\ land)
\end{aligned}
$$

I use the net annual income per farm from the 2012 Agriculture Census ("2017 State Agriculture Overview for Pennsylvania," 2017). There is limited literature to suggest the percent of income lost from retiring land, so I varied income loss between scenarios in the sensitivity analysis. In the median scenario I estimate 10 percent profit losses. I include five percent losses and 20 percent losses in the sensitivity analysis. I accrue the annual losses every year through 2025. I represent costs in 2018 dollars and use a discount rate of seven percent.

Costs to farmers are offset by government payments. I use the average annual payment per acre of retired land from the 2017 Conservation Reserve Program report, which was about \$123 ("Conservation Reserve Program," 2017). I multiply this payment by the number of acres transitioned to land retirement and accrue this payment every year through 2025. These payments total to about \$621 million.

I subtract the government payments from the sum of land retirement costs and income loss to determine the total cost to farmers. I find that in the median scenario, the average cost to farmers is \$264 million.

Caveats:

- I use professional judgement to determine the rate of land retirement and the effect of land retirement on income due to a lack of data. More precise results could be produced if the government obtains better data.
- I assume that all farms retire the same percentage of their land. In reality, farms will retire land as they are financially able. It is beyond the scope of this analysis to assess land retirement at the farm level. The government may wish to group farms into size categories for a more accurate cost estimate.

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