

DERIVED DEMAND FOR BEST MANAGEMENT PRACTICES:  
A NEW PERSPECTIVE ON ADOPTION FROM  
AN EMERGING NUTRIENT TRADING MARKET

by

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## TABLE OF CONTENTS

LIST OF TABLES .....	vi
LIST OF FIGURES.....	vii
ABSTRACT.....	x
1 INTRODUCTION.....	11
Background .....	11
<i>Water Quality in Chesapeake Bay</i> .....	11
<i>Nutrient Trading Markets</i> .....	12
Research Goals and Purpose .....	13
<i>Study Contents</i> .....	14
Review of Literature .....	15
<i>Private Benefits of BMP Adoption</i> .....	15
<i>Costs of BMP Implementation</i> .....	16
<i>Socioeconomic Patterns of Adoption</i> .....	17
<i>Nutrient Offset Trading Criticism</i> .....	17
<i>Contributions to Literature</i> .....	18
METHODS .....	20
Patterns and Limits to Study .....	20
<i>Current BMP Adoption in Maryland</i> .....	20
<i>Non-Quantifiables</i> .....	20
<i>Heterogeneity of BMPs</i> .....	21
Concept of Derived Demand and Firm Production.....	22
<i>Valuation of Natural Resources</i> .....	23
DATA.....	24
Sample of Eastern Shore Fields .....	24

<i>Agronomic Data</i> .....	24
<i>Collecting Data on Sample Fields in MDNTT</i> .....	24
<i>BMP Scenarios and Final Data Set</i> .....	25
<i>Cost Data Extension</i> .....	26
RESULTS .....	29
Heterogeneity of Offset Generation .....	29
Expected Behavior in BMP Market .....	30
Sensitivity of Adoption to stacking or policy subsidies .....	31
CONCLUSION .....	34
REFERENCES .....	36
ASSUMPTIONS USED TO AUGMENT AND RECONCILE .....	66
SURVEY DATA IN NUTRIENT NET .....	66

## LIST OF TABLES

<b>Table 1</b>	Cost Estimates of Best Management Practice Adoption.....	39
<b>Table 2</b>	Estimated Participation Rate for Low-load Fields .....	42
<b>Table 3</b>	Predicted Participation of Low-load Fields with Various Subsidies and/or Bonuses .....	44

## LIST OF FIGURES

<b>Figure 1. Diagram of offset and BMP markets.</b> The diagram on the left represents the ecosystem services offset market where the supply of nutrient offsets comes from nonpoint sources of pollution, and demand for offsets is from point sources of pollution. The diagram on the right represents the market for farmer’s demand for BMPs. The demand for BMPs is derived from the offsets supplied in the offset market.....	45
<b>Figure 2. Nitrogen reductions per acre for decision agriculture scenario.</b> Measured in pounds/acre for the 77 sampled fields, under the 4 BMP scenarios.....	46
<b>Figure 3. Nitrogen reductions per acre for grass buffer scenario.</b> Measured in pounds/acre for the 77 sampled fields, under the 4 BMP scenarios. ....	47
<b>Figure 4. Nitrogen reductions per acre for forest buffer scenario.</b> Measured in pounds/acre for the 77 sampled fields, under the 4 BMP scenarios. ....	48
<b>Figure 6. Phosphorus reductions per acre for decision agriculture scenario.</b> Measured in pounds/acre for the 77 sampled fields, under the 4 BMP Scenarios. The only reduction found under decision agriculture is an error within MDNTT’s calculations since there is no phosphorus efficiency for decision agriculture. ....	50
<b>Figure 7. Phosphorus reductions per acre for grass buffer scenario.</b> Measured in pounds/acre for the 77 sampled fields, under the 4 BMP Scenarios...	51
<b>Figure 8. Phosphorus reductions per acre for forest buffer scenario.</b> Measured in pounds/acre for the 77 sampled fields, under the 4 BMP Scenarios...	52
<b>Figure 9. Phosphorus reductions per acre for land use conversion scenario.</b> Measured in pounds/acre for the 77 sampled fields, under the 4 BMP Scenarios. ....	53

<b>Figure 10. Derived benefits figures for decision agriculture scenario.</b> The 77 sample fields were organized from highest to lowest benefits, and therefore may not correspond with the same field number from the cost estimate figure. Benefits are the total benefits for the entire field generated from implementation of the practice across the entire field. ..	54
<b>Figure 11. Cost figures for decision agriculture scenario.</b> Cost estimates were obtained from Chesapeake Bay Commission Economic Study (2012). The 77 sampled fields estimates were organized from lowest to highest values, and therefore may not correspond with the same field number from the cost estimate figure. Costs are the total cost of applying the practice to the entire field.....	55
<b>Figure 12. Net benefits for decision agriculture scenario.</b> Indicates the difference between net benefits at the high credit price and low cost level (upper horizontal bar), and net benefits at the low credit price and high cost level (lower horizontal bar). Values were calculated by subtracting expected costs of implementation from expected benefits...	56
<b>Figure 13: Derived benefits for forest buffer scenario.</b> The 77 sample fields were organized from highest to lowest benefits, and therefore may not correspond with the same field number from the cost estimate figure. Benefits are the total benefits for the entire field generated from implementation of the practice on an estimated buffer size.....	57
<b>Figure 14. Cost figures for forest buffer scenario.</b> Cost estimates were obtained from Wainger et al. (forthcoming). Costs were applied to an estimated buffer size for each of the 77 fields and represent the entire cost of implementation. Estimates were organized from lowest to highest values, and therefore may not correspond with the same field number from the cost estimate figure. Forest buffer and grass buffer cost curves are scalar transformations due to use of same buffer acreage with different costs.....	58
<b>Figure 15. Net benefits for forest buffer scenario.</b> Indicates the difference between net benefits at the high credit price and low cost level (upper horizontal bar), and net benefits at the low credit price and high cost level (lower horizontal bar). Values were calculated by subtracting expected costs of implementation from expected benefits. ....	59



**Figure 16. Derived benefits for grass buffer scenario.** The 77 sample fields were organized from highest to lowest benefits, and therefore may not correspond with the same field number from the cost estimate figure. Benefits are the total benefits for the entire field generated from implementation of the practice on an estimated buffer size..... 60

**Figure 17. Cost figures for grass buffer scenario.** Cost estimates were obtained from Wainger et al. (forthcoming). Costs were applied to an estimated buffer size for each of the 77 fields and represent the entire cost of implementation. Estimates were organized from lowest to highest values, and therefore may not correspond with the same field number from the cost estimate figure. Forest buffer and grass buffer cost curves are scalar transformations due to use of same buffer acreage with different costs. .... 61

**Figure 18. Net benefits for grass buffer scenario.** Indicates the difference between net benefits at the high credit price and low cost level (upper horizontal bar), and net benefits at the low credit price and high cost level (lower horizontal bar). Values were calculated by subtracting expected costs of implementation from expected benefits. .... 62

**Figure 19. Derived benefits for land use conversion scenario.** The 77 sampled fields were organized from highest to lowest benefits, and therefore may not correspond with the same field number from the cost estimate figure. Benefits are the total benefits for the entire field from the retiring of 25% of field acreage to forest. .... 63

**Figure 20. Cost figures for land use conversion scenario.** Cost estimates were obtained from Wainger et al. (forthcoming), and applied to the size of the retired land for the 77 sampled fields. Estimates were organized from lowest to highest values, and therefore may not correspond with the same field number from the cost estimate figure. .... 64

**Figure 21. Net benefits for the land use conversion scenario.** Indicates the difference between net benefits at the high credit price and low cost level, and net benefits at the low credit price and high cost level. Values were calculated by subtracting expected costs of implementation from expected benefits. .... 65

## **ABSTRACT**

This paper examines the effectiveness of a proposed nutrient offset trading market at increasing adoption rates of best management practices (BMPs) in the Chesapeake Bay Watershed. The analysis incorporates real agronomic data collected from farms on Maryland's Eastern Shore to accomplish three study objectives: (1) derive the farms' demand to adopt BMPs; (2) determine the heterogeneity of nutrient reductions for various farms; and (3) estimate the likely participation in the proposed program. Seventy-seven low-load fields were entered into the Maryland Nutrient Trading Tool where reductions were calculated from the planned installation of four management practices: Forest and grass buffers, decision agriculture, and land use conversion. Estimated costs of BMP adoption and credit values were applied to generate net benefits of adopting a BMP in the offset trading market, from which participation was then estimated. The results showed the trading tool creates heterogeneous reductions in nutrient loadings. Second, the incentives derived from the program are only likely to incentivize riparian buffer adoption, a practice that is likely already fully incentivized. This may lead to low participation rates within the program. Finally, adoption rates could be increased through the incorporation of unmeasured and additional benefits, though doing so could create a distortion within the market.

## Chapter 1

### INTRODUCTION

#### Background

##### *Water Quality in Chesapeake Bay*

The deteriorating health of the Chesapeake Bay is on the forefront of environmental concerns. Due to its large size branching into six states and the District of Columbia, cooperation from many parties is needed in order to meet the requirements established under the Clean Water Act (CWA). Furthermore, the importance of establishing new programs to reverse human impact will be even more critical, as the human population within the watershed is expected to increase by 2 million people in the next 20 years (Van Houtven, et. Al. 2012). To combat this issue, the Environmental Protection Agency has established Total Maximum Daily Load (TMDL) requirements in the Chesapeake Bay Watershed, which are essentially the maximum loadings of nutrients, nitrogen (N) and phosphorus (P), in each segment that can enter the Bay without further degradation of water quality. These segments are broken up among jurisdictions and major river basins.

Under these TMDL requirements, each segment is required to create and enforce a Watershed Implementation Plan (WIP), which indicates how that segment will make reductions in order to meet TMDL standards. These nutrient loadings into the Bay come from two main sources, point and nonpoint. Point sources of pollution include wastewater discharge from industrial facilities, which can be directly regulated under the CWA, and account for approximately 20% and 19% of nitrogen and phosphorus loadings, respectively (Van Houtven, et. Al. 2012). Other contributors of nutrient loads

come from various other nonpoint sources, which are difficult to monitor and are not regulated under the CWA. The most significant of these sources are contributions from nutrient runoff of agricultural lands, responsible for 42% of nitrogen and 54% of phosphorus contributions (Van Houtven, et. Al. 2012). When comparing nutrient contributions between these sources, it becomes apparent how important reducing agricultural loads are to improving Bay quality (Van Houtven, et. Al. 2012).

Most agricultural decisions are free from direct federal regulatory control (mainly, under the Clean Water Act), but states must nevertheless comply with federal TMDLs that establish mandatory performance levels of nutrients. States have looked to innovative policies to incentivize reduced loadings from agriculture, but have resisted efforts to exert direct regulatory control over this sector. Instead, state and federal agencies have focused on promoting and incentivizing the adoption of best management practices (BMPs) by agricultural producers.

TMDLs affecting the Chesapeake Bay create opportunities for economists to examine the new incentives facing managers of nonpoint sources created by this institutional change. States in the Chesapeake Bay Watershed are building their own policy and technical infrastructure to support point-nonpoint water quality trading, in part, as an incentive (through purchased offsets) to reduce loadings from agriculture. Agricultural BMPs play a role in each emerging trading program. This paper describes evidence from an application about why the emerging trading markets may not work as anticipated.

### *Nutrient Trading Markets*

The goal of nutrient trading markets is to supply load reductions from nonpoint sources at a lower cost than point sources may be able to achieve. This creates flexibility for industrial point sources of pollution to meet regulations by either implementing reduction technologies or through purchasing offset credits (i.e., load reductions from

nonpoint sources). These offset credits are generated in different ways depending on the framework of the program. The largest difference between programs is the establishment of a baseline requirement, a level of performance that must be met by nonpoint sources in order to participate. Baselines are either established by date, where all further nutrient reductions through BMP implementation after an established date generate credits, or by performance, where sources must be below a certain load requirement before further reductions from adoption are credited. The establishment of a baseline type is a determining factor in offset credit generation. This study focuses on Maryland's Nutrient Trading Program, which utilizes a performance-based standard.

### **Research Goals and Purpose**

One motivation for Bay trading programs seems to be that the additional incentive provided by the offset market will push agricultural landowners and managers over the positive private net benefit threshold, thus triggering broader BMP adoption. This leads directly to the research question posed in this paper: What are the likely adoption patterns? In other words, what are the participation incentives created by the new offset markets? This is an important question because, if scientific evidence exists that the incentive currently provided by the existing offset market is insufficient to attract the participation desired by policy makers, then the offset market should be further refined before property rights are firmed up by substantive trading activity. Of course, the offset market incentive comes directly from the incentives created by the cap on points, the baseline for agricultural nonpoints (which reflects the TMDL allocation), and allocation mechanism for distributing offset credit to nonpoints (affected by policy-manipulable variables such as uncertainty factors and trading ratios).

### *Study Contents*

This thesis presents the analysis of the offset productivity of 77 farm fields in the Eastern Shore of Maryland, as computed by the state's performance based trading software market--the Maryland Nutrient Trading Tool (MDNTT, at <http://www.mdnutrienttrading.com/>). Survey data from agricultural scientists were used to calculate the offsets generated by adoption of four potential BMPs on each field. The Trading Tool provides automatic "stacking" of N and P offsets, providing a single aggregate incentive for adoption. Stacking is the process where the reductions for each nutrient are combined to yield total benefits from BMP implementation, when in reality, individual nitrogen and phosphorus reductions could be sold separately. This incentive, which is measured in pounds of abatement, is multiplied by a range of prices anticipated in a functioning market. This is, in effect, the derived demand (marginal revenue product) by a farmer for adoption of a given BMP--derived solely from the new trading market. These derived demands are compared to estimate BMP costs of adoption (marginal resource cost) collected from the literature. The analysis leads to three sets of conclusions about adoption in the BMP market, derived from the offset market--which to our knowledge is the first study of this kind.

The first conclusion is that the trading tool produces a great deal of heterogeneity in offset production, which means that participation will be sensitive to offset price over a range of prices. Second, over a realistic range of offset prices, the incentives created are more likely to incentivize buffer-type BMPs than more expensive land use conversion and low-productivity decision agriculture. A third set of results focus on the sensitivity of adoption decisions to a range of unmeasured, additional potential benefits from each BMP. These might include private benefits, stacked benefits from other programs, joint effects as with an economy of scale in adoption of a different BMP, and potential subsidies, which could be awarded outside of the trading system.

## **Review of Literature**

The literature examining BMP adoption is extensive. This study has focused on reasoning and factors behind the choice to implement BMPs on a farm. First, farms evaluate the private benefits and costs they could expect to encounter from implementation. Studies have also evaluated the socioeconomic factors and patterns involving BMP adoption. Literature has also expressed a general sense of skepticism towards the use of nutrient offset trading to combat water quality issues with point and nonpoint sources. One area that has not been thoroughly investigated the producers demand for BMP adoption, a topic that this study addresses. Findings will help contribute to the existing cost studies of BMP adoption, as well as offer estimates of expected participation in the market under current conditions.

### *Private Benefits of BMP Adoption*

A number of studies have assessed the private benefits accruing to producers, and they generally conclude farms benefit from BMPs through on-field increases in efficiency, as well as increased property aesthetics. Weiland et. al (2009) found that farmers implementing BMPs experienced a decrease in costs and had the potential for increased crop yields due to better conservation of on-field nutrients. Farmers that implemented no-till agriculture on their fields also experienced an increase in output when used over an extended period of time. Lynch et. al, (2000), found the existence of other values such as nonuse values from BMPs, including increased field aesthetics from the creation of grass or forest buffers. These increased aesthetics could in turn create habitat for wildlife, as well as increase property value. Others (Reimer et. al, 2009) have also found benefits of increased wildlife habitat, as well as additional benefits of increased social prestige, reduced discomfort, conservation of soil, and the perception of having an advantage over other farmers via time-savings and environmental benefits.

Farmers also found benefited from owning a farm that gave off the overall appearance of being well taken care of (Reimer et. al, 2009).

### *Costs of BMP Implementation*

Many studies have sought to describe adoption behavior more fully by either estimating some of the costs of adoption or other characteristics of BMP supply and overall concluded that farms experience the costs of installation, maintenance, option, and opportunity costs. The estimation of BMP costs must cover several key components of the implementation of BMPs. The most obvious costs would be the upfront costs of installing the practice, or the installation costs. These would encompass the initial time, labor, and capital needed for implementation. Once installed, the original quality of the practice must be maintained throughout its lifespan. These costs are known as maintenance costs and include the time, money, and labor required to repair, maintain, and monitor the effectiveness of the practice.

The decision to implement a practice also has option values associated with it. This is the idea that value exists in the decision to implement by way of taking away possible options for use in the future. Transaction costs for participating in the program could also impact costs of adoption. In many cases, an aggregator may be used to compile the farms information and register them in the trading program, services that would require compensation. These transaction costs would also include the time the landowner would dedicated to paperwork and other program requirements (Lynch, et. Al. 2000). Regulators of the program would also bear some of the costs of monitoring and possibility of cheating the program.

Finally, opportunity costs need to be considered to fully capture entire costs. Opportunity costs would include the value of the next best use on that land forgone for implementation of a BMP. For example, the opportunity cost of converting a portion of



ones cropland to a riparian buffer is the value that could have been generated from leaving that land in production (Weiland, et. Al. 2009).

### *Socioeconomic Patterns of Adoption*

Existing literature also explains socioeconomic patterns in adoption and predominately concludes that a lack of knowledge and fear of reduced profit are the biggest determinants in adoption patterns. One of the most widely examined questions is why farmers decide to forgo BMP adoption. One of the primary factors for lack of BMP adoption is a general lack of knowledge on the existence and benefits of adoption (Feather, et. Al. 1994). The most cited reason farms do not adopt a BMP is a lack of familiarity with the practice and uncertainty as to whether or not that particular practice applies to their farm (Gillespie, et. Al. 2007). In addition, others had fears of reducing profitability of their operations or felt there were not enough existing incentive programs to make BMP adoption a profitable option (Paudel, et. Al. 2008). Also, farmers receiving income from off-farm employment had higher adoption rates of capital-intensive BMPs. This shows that lack of sufficient funds or knowledge could be a limiting factor to BMP adoption (Gedikoglu, et. Al. 2011). Through further examination of BMP profitability, existing incentive programs, and increased knowledge of existence could help to further increase BMP adoption.

### *Nutrient Offset Trading Criticism*

Some studies have highlighted the skepticism that exists regarding the effectiveness of nutrient trading, concluding that the current design of the program will prevent it from functioning properly. Stephenson et. Al. (2010) believes several flaws in the system will hold this program back from being successful. Many of these are associated with costs such as costs accrued by the farmer to participate may outweigh the opportunity costs of participation (Stephenson et. Al., 2010). On the other side of the

sector, Stephenson et. Al. (2010) believes there will be a lack of buyers of agricultural credits due to credit prices being too high, estimate of \$100 per credit of nitrogen in a similar Virginia program, as well as the requirement to still meet minimum technology standards. On a larger scale, Shortle et. Al. (2010), found policy design problems such as who to target, how to measure compliance, how to encourage further BMP adoption on a socioeconomic basis such as further economic incentives or direct regulation.

### *Contributions to Literature*

No evidence exists on producer's demand for BMPs. This paper will argue that the incentives derived from the Maryland Nutrient Trading program are not great enough to incentivize broad participation from Eastern Shore farmers. This contributes to the literature by first, being the only study to impute the incentive for adoption of BMPs through a nutrient trading platform. This, therefore, complements the more common cost-side studies. Contributions will also be made through the examination of expected market participation without having to wait and observe the actual market performance.

Previous scholarly articles and studies are not based on revealed preference data. In the ecosystem services market, farmers supply reduction credits into that market based on their willingness to accept payments for these services. The demand in that market for ecosystem services comes from the government's decision about how to restrict point sources, which triggers their need for offsets.

In this study, we are using information to infer the supply curve in this market, and utilizing that to show the demand curve to adopt these practices from the inferred incentives. This recognizes that two markets exist for ecosystem services and BMP adoption, one market for BMP services, and one market for offsets. The abatement market determines how many offset credits will be supplied by nonpoint sources of pollution, and how many will be purchased by point sources of pollution. The BMP

adoption market, the focus of this paper, determines the quantity of BMPs that will be supplied (derived from quantity of offset credits supplied in the ecosystem services market), compared to the cost of BMP adoption. A visual interpretation of these markets can be seen in figure 1. The lack of information on the farms demand for BMPs expresses a need for new data on BMP adoption that is revealed through actual market incentives. This also allows for the ability to determine willingness to accept for BMP implementation.

Conservation Reserve and Enhancement Program (CREP) and other cost sharing and incentive programs offer some incentive for farmers to adopt BMPs. However, statistics show that many do not participate in these cost-sharing programs (Lichtenberg, et. Al., 2010). Nutrient trading could serve as a viable solution to the compliance issues currently faced by state institutions. These programs could offer greater incentive for farms to adopt BMPs by making them more profitable. This would create another source of revenue generation for farmers. The nutrient trading program could also serve as an alternate route to cost sharing programs.

This paper will contribute to existing literature and studies involving BMP implementation in several different ways. First, it will add economic insight on the likely performance of the proposed nutrient trading institutions. It will also complement studies being done on BMP costs for farmers to supply BMP services in a market. Finally, it will help predict participation in the program in advance, which may aid in the design of a more effective policy.

## Chapter 2

### METHODS

#### Patterns and Limits to Study

##### *Current BMP Adoption in Maryland*

This section examines the benefits and costs affecting the demand by producers to adopt best management practices. Current trends in Maryland show low or no adoption rates of BMPs, as well as low enrollment in cost-sharing programs. Lichtenberg et al. (2010), found evidence in Maryland that among farms with crop operations 41.8% implement conservation or no-till but only 3.8% receive cost sharing. As for the retirement of highly erodible farmland, 6.8% of the subset implemented, and only 1% used a cost share program. They also found that 32.7% of farms implemented a riparian buffer, but only 10.3% received cost share money. This suggests that a small subset of farmers find these practices to be optimal, while others need cost share. An even greater set do not adopt under the current cost share programs. This shows a void exists in effectively incentivizing BMP adoption—a gap offset trading could possibly fill.

##### *Non-Quantifiables*

Varying levels of BMP adoption and enrollment in cost-sharing programs show how farm management differs across farms. The differences in management techniques are largely due to differences in optimal farm size and intensive factors like labor and equipment. For example, farm 1 may choose to devote a certain number of acres of his field to implement a riparian buffer, causing a decrease in field size. Farm 1 may already

have the ideal equipment that deals well with the remaining field size, causing little or no change in the optimal field size. However, farm 2 may have different existing equipment that is ideal for a larger field, where converting a portion of his field to a riparian buffer would make inefficient use of his equipment and requiring more labor, which would have effects on marginal revenue product. These factors are unquantifiable from the researcher's perspective because it is very difficult or impossible to account for the differences in costs and benefits of BMP adoption as it affects economies of scale. It is also difficult to see how those farms would deal with the changes in management techniques. For this reason, this study assumes that the adoption of BMPs changes the farms technology in the same way. Here we acknowledge that in reality some farms will experience more or less harm and benefit than others.

#### *Heterogeneity of BMPs*

The benefits and costs a farm experiences from BMP adoption are heterogeneous. This study recognizes that heterogeneity exists in farms' ability to produce nutrient reductions from the same BMP. This study develops a revealed measure of this heterogeneity. However, we have assumed homogeneous costs for BMP adoption across all farms, when in reality, costs will be heterogeneous as well. Firms may experience differences in costs for several reasons including differences in production processes, geographic location, firm size, and availability of certain technologies (Van Houtven, et. al., 2012). The heterogeneous benefits that we recognize may be correlated with heterogeneous costs, resulting in a potential source of systematic bias.

It is very difficult to determine the pattern between heterogeneous costs and benefits. For example, a farm that generates a high level of benefits could be either a high cost farm or a low cost farm. There is no real way to make this determination. If that high benefit farm has a negative correlation to costs (making it a low cost farm),

then participation will be higher than what we predict. Likewise, if a low benefit farm were also a high cost farm, participation would be lower than predicted.

### **Concept of Derived Demand and Firm Production**

In order to predict participation, the farmers' demand for adopting a BMP must be calculated. The method of doing so will use the concept of derived demand, the idea of imputing the demand for inputs by looking toward the revenue production in an output market. The demand for these inputs comes from the demand for the final goods. In this case, the demand for farms to adopt a BMP comes derived from the demand for offset credits in Maryland's trading program from point sources of pollution. This exhibits the value that supplied BMPs add to the final value of credits in the market. The demand for inputs arises from two different sources. First, it reflects how the input contributes to production, known as marginal physical product (MPP), which in this case represents the credits or pounds of nutrient abatement. The demand for an input is also affected by the price of the final good, which would be the market price for credits in the offset market.

The MPP and market price can be multiplied to show the total value added by the input unit, revealing the marginal revenue product (MRP). In sum, providing an additional BMP in the nutrient trading market yields additional revenue, which is the value added by a BMP, the number of reductions (credits) multiplied by the market price for credits. An increase in the number of BMPs that are adopted will increase the number of available credits in the market (Seitz, et. Al., 2001).

The creation of marginal revenue product is only one half of the decision of whether or not to adopt a BMP. The producer must also consider the cost of supplying that BMP, known as the marginal resource cost (MRC), or the cost of supplying an additional unit of input. Farms ideally want to maximize profits in the trading market by

continually providing BMPs until the cost of supplying exceeds the benefit of supplying, or where  $MRP=MRC$  (Seitz, et. Al., 2001).

### *Valuation of Natural Resources*

This concept can be applied to the valuation of natural resources. On their own, natural resources only have instrumental value, they are only valued due to the fact that they produce some other final good that generates revenue. The value that gets placed on natural resources is derived from the fact that they can produce something else, such as reductions in nutrient loading. For example, a riparian buffer would generate its value from the fact that it reduces the amount of nutrients entering the Chesapeake Bay, a service for which point sources are willing to pay so that they can avoid higher abatement costs. This shows the unique attribute of natural resources having value creation ability. If this ability to produce net returns in the future were to dissipate, it would render them essentially valueless (Cramer, et. Al. 1988).

## Chapter 3

### DATA

#### Sample of Eastern Shore Fields

##### *Agronomic Data*

This study extends the analysis of data originally reported in Duke et al. (manuscript). Only a brief summary of the data collection is reported in that manuscript is reviewed herein. First, collaborators at the University of Maryland collected agronomic data for 196 fields on Maryland's Eastern Shore. They targeted fields with FIV (fertility index value) +150, as well as fields that were more likely to cooperate with the data collection based on recommendations from nutrient management planners in the University of Maryland's Extension offices. Due to the fact that the collection targeted farmers that cooperated with nutrient management regulations, one expects that these farms might be more likely to participate in a nutrient trading program, or are more likely to have BMPs in place. The data set may also be slightly biased to farms that continually used manure fertilizer, as seen by the higher FIV. Finally, some fields may be managed by the same operator, which could lead to more similar management practices than would normally be seen in the entire population.

##### *Collecting Data on Sample Fields in MDNTT*

The 196 fields were systematically entered into Maryland's Nutrient Trading Tool (MDNTT). The trading tool takes into account the agronomic data that reflects the farmers on field activities such as fertilizer application, crop rotation, location, and soil type. A list of assumptions made for the data entry process can be found in Appendix A.



Through a series of calculations through several different models, the program is able to give an output of estimated current loads of nitrogen and phosphorus measured in lbs/acre. This load is compared to the baseline load, and a message tells the user whether or not that specific field meets the baseline requirements. If a field does not meet the baseline requirements, they are not eligible to continue until they are below baseline. Of the 196 fields, 7 were unable to be entered into MDNTT due to lack of data in certain areas. Of the 189 fields left in the sample, 77 (40.7%) met baseline requirements for both nitrogen and phosphorus, prior to the implementation of any BMP.

#### *BMP Scenarios and Final Data Set*

Next, the fields that met baseline requirements had BMPs input into MDNTT. In Duke et al. (manuscript), seven specific BMPs were applied one at a time on each field. For this study, only four BMPs were used, grass and forest buffers, decision agriculture, and land use conversion, due to the existence of cost studies for these practices. The BMPs of conservation planning (high and low till), and water control structure were dropped due to lack of cost studies. Descriptions of these practices can be found in Duke et al. (manuscript).

The BMP decision agriculture was applied to the size of the entire field. Land use conversion meant that 25% of the entire field transitioned from crop to a forest. Forest and grass buffer sizes were calculated through a series of steps. First, each field was located in a GIS program, and the side of field closest to surface water was determined. Then the length of that side of the field nearest to the surface water was measured, being the area a buffer is most likely to be implemented. The buffer length (in feet) was multiplied by 45 ft., which represented the expected width of the buffer, and was then divided by 43,560 ft. to get the acreage of that buffer. The same buffer acreage was used for both forest and grass buffers. Since different sized buffers were implemented on each field based on realistic size estimates, heterogeneity of reduction

generation came from two sources, the size of the buffer, as well as varying levels of productivity accounted for in MDNTT.

Following this, MDNTT estimated future load reductions for nitrogen and phosphorus. These future reductions represent the possible offsets that could be sold in the trading market. Each BMP was run one time for every one of the 77 fields, giving 77 different expected reductions for each of the four BMPs. These reductions were measured as reductions per acre so that all BMPs could be evenly analyzed. As seen in figures 2 through 5, the nitrogen reductions were organized from highest amount of reductions per acre to lowest amount of reductions and plotted on the same axis. This appears as a downward sloping line showing the expected reductions across the 77 fields. The same was done for phosphorus reductions, as seen in figures 6 through 9.

#### *Cost Data Extension*

The final step was to incorporate cost values into these figures as an extension to the study found in Duke et al. (manuscript). These expected reductions could be rounded in order to generate expected credits to be sold in the market. However, for this study, reductions were left unrounded in order to prevent distortion of actual reductions. If the reductions were rounded on the per-acre level, it would have a large impact on small fields. By applying an estimated monetary value of these reductions in the trading market, the expected revenue from trading can be determined. These values would then be seen as benefits to the farmer from participating and implementing these practices. Due to the uncertainty of what values these credits will accrue, the estimates from Duke et al. (manuscript) of between \$4 per credit and \$20 per credit were used for nitrogen, and between \$20 and \$100 for phosphorus. These values can be interpreted as dollars per year received for each practices, over 77 different fields for high benefits (\$20 nitrogen, \$100 phosphorus per credit) and low benefits (\$4 nitrogen, \$20 phosphorus per credit). These expected benefit figures are seen in figures 10, 13, 16, and 19.

By examining the costs a farmer might expect to incur for the addition of the BMP to their field, it can be seen whether or not one could expect to gain back their initial investment through trading. Table 2 serves as a collection of cost estimates for several BMPs, organized by the type of best management practice. Some best management practice costs have not been studied enough to provide a precise estimates. These practices include conservation planning and water control structures. The costs for the four practices were measured in dollars per acre per year and annualized over different periods of time depending on the source, as indicated in table 2.

Each cost study considered different types of costs, which included initial capital, costs, operation costs, maintenance, labor, instillation, and opportunity costs. Because there are many possible cost ranges to use and we have no evidence on what is correct, we focus on cost estimates from a study conducted by Wainger et al. (forthcoming), for unit costs for selected BMPs. Wainger et al. (forthcoming) is recent study that just went through peer review. This study was also chosen for the source of homogenous BMP costs due to the inclusion of installation, operation and management, and opportunity costs of converting the land (measured as cash rental rates for crop land). This study incorporated costs from Wieland et al (2009), but had a much more concentrated range of high and low estimates. We felt that costs and capabilities of the fields in this study are closely related due to the closeness of their geographic location, matching that of the more concentrated cost range. Only one study provided cost estimates for decision agriculture, therefore the Chesapeake Bay Commission: 2012 Economic Study was used to represent these costs. The high and low estimate lines were applied to the four practices, as seen in figures 11, 14, 17, and 20. These fields were organized from lowest costs to highest costs. For this reason, fields in the costs and benefits figures may not directly correspond with each other. As mentioned previously, because the same buffer size was used for both grass and forest buffers, the cost curves

seen in figures 14 and 17 are scalar transformations of each other based on differences in costs.

Another way to examine the expected benefits and costs from BMP adoption is to look at the net benefits, as seen in figures 12, 15, 18, and 21. Net benefits were calculated at the four possible credit price and BMP cost levels. The vertical bars in these figures represent the possible range a farmer's net benefits would be expected to fall, after total costs were deducted from total benefits. The area located above the vertical axis would represent a farmer with positive net benefits, and who would be expected to participate in BMP adoption in the trading program. The uppermost point for each field represents net benefits at the high credit price (highest benefit level) and low cost level. The lowest point for each field represents the net benefits at the low credit price (lowest benefit level), and highest cost.

## Chapter 4

### RESULTS

#### **Heterogeneity of Offset Generation**

The first result is that MDNTT produces significant heterogeneity in the production of offset credits for each individual field, in this case seen as reductions per acre (lbs/acre). This can be seen through the comparison of figures 2 through 9, which show expected nutrient reductions across the 77 sampled fields for the 4 tested BMPs. As shown, generation of reductions varies across each BMP for both N and P values.

For nitrogen reductions, as seen in figures 2 through 5, forest buffers generated the greatest number of reductions per acre. Reductions per acre ranged from 0.11 to 7.46, with a mean value of 2.02. Following forest buffers were grass buffers, generating 0.08 to 5.41 pounds of reductions per acre, with a mean value of 1.47. Land use conversion generated a minimum of 0.32 and maximum of 3.01 pounds reduced per acre with a mean value of 1.27. Finally, decision agriculture reductions per acre ranged from 0.06 to 0.45, with a mean value of 0.22 pounds per acre.

Phosphorus reduction generation was lower than that of nitrogen, as seen in figures 6 through 9. In MDNTT, decision agriculture has no reduction efficiency for phosphorus. However, an error was found where one field had a reduction of 0.02 pounds of phosphorus per acre. Because this reduction would be rounded to zero credits, it does not impact credit generation, though the error should still be acknowledged. This leads to a range of phosphorus reductions for decision agriculture from 0 to 0.02 pounds per acre and a mean value of 0. Land use conversion produced a range of reductions from 0 to 0.58 pounds per acre, with a mean value of 0.20. Grass buffer reduction

generations were slightly lower, ranging from 0.01 to 0.38 credits per acre with a mean of 0.13. Finally, forest buffer phosphorus credit generation ranged from 0.02 to 0.52 pounds per acre, with a mean of 0.16.

This heterogeneity only became apparent when we used the trading tool's performance-based calculator to reveal the heterogeneity in nutrient reductions. We then connected the heterogeneity in reductions to the BMP market through the concept of derived demand. The marginal revenue product accruing to farms from the adoption of best management practices under Maryland's Nutrient Trading Program could be measured through applying credit values to reductions. The price of these credits comes directly from the nutrient trading market. However, the demand for these reduction credits comes from the point sources of pollution looking to purchase these reduction credits from non-point sources. Further, the expected participation in the program actually comes from the farms decision to enroll based on the private benefits they could expect to generate. Although there are a lot of studies on the adoption of BMPs, we are unaware of any study modeling the BMP adoption market. This result should promote research on this approach to thinking about adoption.

### **Expected Behavior in BMP Market**

Through the creation and calculation of demand for BMPs, the expected behavior in a BMP market can be explained. This was accomplished through comparison with homogeneous cost found in existing literature. BMPs are expected to be adopted to the point where the producer's marginal resource cost (MRC) is equal to their marginal revenue product (MRP), more simply, until costs exceed benefits. These expected participation rates were generated for the 4 combinations of estimated high (\$20/N credit, \$100/P credit) and low (\$4/N credit, \$20/P credit) credit prices, and expected per-acre BMP cost (high or low).

Table 3 shows these expected participation rates across the 4 observed BMP practices. Participation occurs when MRP exceeds MRC. Under the grass buffer scenario, participation was found at all levels, beginning at 1.3% for the least ideal combination of low credit price and high BMP cost. Participation increased to 42.9% participation when the lowest per-acre BMP costs were applied. An approximate 10% increase was reached at the high benefit and high cost level, before reaching full participation at the most ideal high benefit and low cost estimates. Forest buffers saw the same initial participation level at the low credit price and high BMP cost level. A similar large increase in participation was seen at the low credit price and low cost level, as well as at the high credit price and high cost level, up to 37.7% and 98.7% respectively. Full participation was reached at the high credit price and low cost level. Decision agriculture showed no participation at any BMP cost and per-acre credit price level. Land use conversion showed no participation at the low credit price levels, but showed moderate participation at the high credit price level, ranging from 24.7% for the high BMP cost to 71.4% for low BMP cost.

### **Sensitivity of Adoption to stacking or policy subsidies**

The third set of results involves the examination of the sensitivity of BMP adoption in relation to unaccounted for and additional potential benefits from BMP adoption. As mentioned earlier, these could include private benefits, stacked benefits from other programs, joint effects seen in an economy of scale in adoption of additional different BMPs, and potential subsidies from other organizations outside of offset trading.

The researcher has an imperfect ability to derive benefit estimates that fully capture all benefits accruing to BMPs. An example of this could be the retention of on field nutrients through BMP adoption, which would allow farmers to apply less in the future which could potentially lower overall costs. Other benefits, as mentioned earlier,

that may have been missed include the potential for increased crop yields, improved farm aesthetics, the creation of additional wildlife habitat, and perceived advantages over other farmers such as increased social prestige, time savings, environmental benefits, and an overall appearance of a well maintained farm. These additional benefits could provide further incentive for BMP adoption beyond the benefits obtained through trading in the offset market, possibly further increasing BMP adoption.

BMP adoption may also be influenced through the stacking of additional benefits or through other potential programs, additional private benefits, or economies of scale for adopting different BMPs. In this study, the benefits of nitrogen and phosphorus credit generation were stacked. However, other stacking from other potential programs was not, leading to the possibility of higher benefits through BMP adoption on the margin. Some BMPs may also be directly or indirectly subsidized which would also lead to higher accruing benefits. For these reasons, we estimated participation at additional benefit levels above that of the price assumptions made in the BMP trading market. An average cost was assumed between the high and low cost estimates used in the study, as was an average of the assumed N and P credit prices. Then, additional subsidy levels of \$0, \$10, \$50, and \$100 per acre of BMP were applied to each scenario.

The results, found in table 4, show the general trend that BMP adoption can be increased through the addition of further incentives and subsidies. The effects of the subsidies or bonuses had varying effectiveness across the four BMP scenarios. Decision agriculture showed no initial participation at the average cost and benefit level. No further increase in participation was found at the \$10 bonus level. However, full participation was reached at the \$50 bonus level. This shows that those implementing decision agriculture are all similar in regards to how many further benefits they would require in order for implementation to be profitable. However, it would require a substantial amount of increased benefits in order to make it profitable, which may not be likely. Forest and grass buffers experienced very similar trends in participation. Both



practices began with an initial participation of 94.8% at the average cost and benefit level. An increase in participation of 1.3% for both practices was seen at the increased benefit level of \$10 per acre of buffer. Grass buffers then reached full participation at the \$50 bonus level, where it took forest buffers \$100 in increased benefits to reach full participation. Land use conversion began at a very low initial participation of 2.6%. Only a small increase was experienced with \$10 of increased benefits to 5.19%. Increases of 23.4% and 20.8% were seen at the \$50 and \$100 bonus levels, respectively, and reaching a maximum participation of 49.4%.

## **Chapter 5**

### **CONCLUSION**

The objective of this study was to determine the possible adoption patterns and incentive to participate in the adoption of BMPs in this offset market. It was found that incentives generated within the trading program would not be great enough to incentivize broad participation in the program. Based on the results of this study, Maryland's Nutrient Trading Program alone is unlikely to generate or lead to further adoption of BMPs under the assumed credit prices. The BMPs experiencing highest proposed adoption rates were for that of riparian buffers, but these are already addressed more comprehensively by state land use policies and by federal conservation programs. This means that those most likely to adopt in the offset market would have already been affected by existing policies and, with the exclusion of cost-shared BMPs, the offset market is less likely to trigger a great deal of new adoption.

In order to meet the desired nutrient reductions, changes may have to be made. Under the assumed conditions, the benefit level accruing to farmers must increase in order to increase participation and BMP adoption. If the supply of credits does not meet the demand for offsets from point sources, these point sources of pollution will have to supply their own abatements in order to comply with the TMDL requirements. A lack of offset credit supply could lead to reductions not being provided in the most cost efficient way. One of the ways to increase the benefit level would be to restrict the supply of credits by making baseline requirements more stringent. A lower supply of credits would increase their value.

It has also been found that additional subsidies or bonuses stacked on acknowledged benefits could trigger higher adoption rates. However, if nonpoint sources

are the parties receiving the subsidies, the offset market could be distorted. Increased benefits would shift the BMP supply curve to the right; meaning suppliers of BMPs would be able to do so at a lower cost, which creates a distortion. If the subsidy takes the form of a stacking bonus, then it would be non-distortionary. In that case, the bonus would be internalized and would not actually be a subsidy.

The biggest issue found through this research is not the lack of participants, but rather who is likely to participate. Actual participants likely to enroll in the program will be current providers of BMPs. Because the BMP would already be in place, the cost of supplying would essentially be zero. The nutrient reductions stemming from BMPs that are currently in place would be already felt by the Chesapeake Bay. This poses several potential policy problems. One problem is additionality; if the incentives are low, then those most likely to participate will have very low costs and the ones with the lowest costs are those currently supplying the ecosystem services. These reductions would already be accounted for in TMDLs, leading to nonadditional reductions. If credit were to be given to these nonadditional reductions and sold to point sources, the loading into the watershed has the potential to actually increase.

Information provided by this research should be used to make further refinements to Maryland's Nutrient Trading Program, as well as to other offset trading markets. These changes should be done before full-scale operation, after which would be much more difficult. It is also important to prevent credit generation for best management practices currently in place, where reductions are already felt by the bay. Doing so is crucial in the prevention of increased loading into the Bay.

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**Table 1** Cost Estimates of Best Management Practice Adoption

Cost Estimate (acre/year)	Annualization Period (years)	Costs Considered	Source
Forest Buffer			
\$108	25	Includes initial capital, operations and management costs	Chesapeake Bay Program: 2003 Cost Survey
\$98-\$903	15	Includes opportunity, instillation, and annual maintenance costs	Chesapeake Bay Commission: 2012 Economic Study
\$218-\$729	15	Includes instillation, labor, and maintenance costs, larger estimate includes labor and resource costs of hiring a contractor	Maryland Cooperative Extension: Fact Sheet 774
\$163-\$291	15	Includes opportunity, instillation, and annual maintenance costs	Lisa Wainger (forthcoming)
Grass Buffer			
\$17	10	Includes initial capital,	Chesapeake Bay

		operations and management costs	Program: 2003 Cost Survey
\$44-\$632	15	Includes opportunity, instillation, and annual maintenance costs	Chesapeake Bay Commission: 2012 Economic Study
\$168-\$400	15	Includes instillation, labor, and maintenance costs, larger estimate includes labor and resource costs of hiring a contractor	Maryland Cooperative Extension: Fact Sheet 774
\$99-\$226	15	Includes opportunity, instillation, and annual maintenance costs	Lisa Wainger (forthcoming)
Land Retirement			
\$17	10	Highly erodeable land, Includes initial capital, operations and management cost	Chesapeake Bay Program: 2003 Cost Survey
\$19-\$903	15	Includes opportunity, instillation, and annual maintenance costs	Chesapeake Bay Commission: 2012 Economic Study
\$129-\$257	15	Includes opportunity,	Lisa Wainger



		instillation, and annual maintenance costs	(forthcoming)
Decision Agriculture			
\$13–\$30	1	Includes opportunity, instillation, and annual maintenance costs	Chesapeake Bay Commission: 2012 Economic Study

Source Notes: Cost estimates were collected from

(1)[http://www.chesapeakebay.net/content/publications/cbp\\_13206.pdf](http://www.chesapeakebay.net/content/publications/cbp_13206.pdf) (Exhibit 16, pg. 70.),

(2)<http://www.chesbay.us/Publications/Nutrient%20Trading%20Appendix/Appendix%20B%20Ag%20BMPs.pdf> (Table B-2), Lynch, L., et al. (table 1, table 2), Wainger, L. et al. (table 2).

**Table 2** Estimated Participation Rate for Low-load Fields

Practice	Per- Acre	Per-Acre	Expected
	Credit Price	Cost for BMP	Participation (%)
Grass Buffer	Low	High	1.3
	Low	Low	42.9
	High	High	54.5
	High	Low	100.0
Forest Buffer	Low	High	1.3
	Low	Low	37.7
	High	High	98.7
	High	Low	100.0
Decision Ag	Low	High	0
	Low	Low	0
	High	High	0
	High	Low	0
Land Use	Low	High	0
Conversion	Low	Low	0
	High	High	24.7
	High	Low	71.4

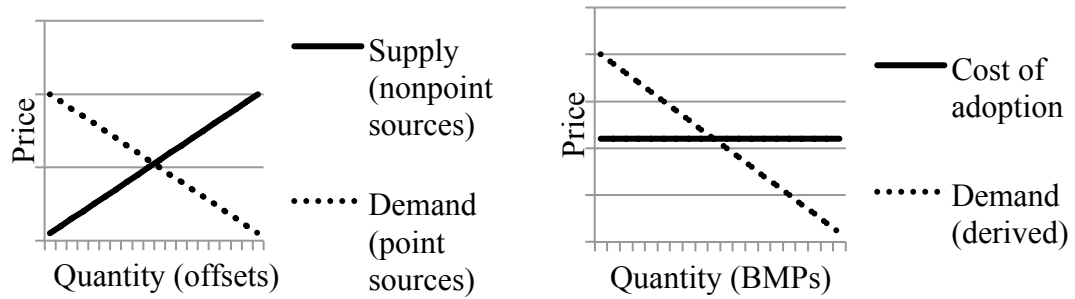
Notes: Data show expected participation rate in Maryland's Nutrient Trading program for the 77 sampled fields. The high and low BMP costs can be found in table 2. Estimated high credit prices were \$100/credit of P and \$20/credit of N.

Estimated low credit prices were \$20/credit of P and \$4/credit of N. A field was expected to participate when the benefits of trading exceeded the costs. These are original calculations for this paper.

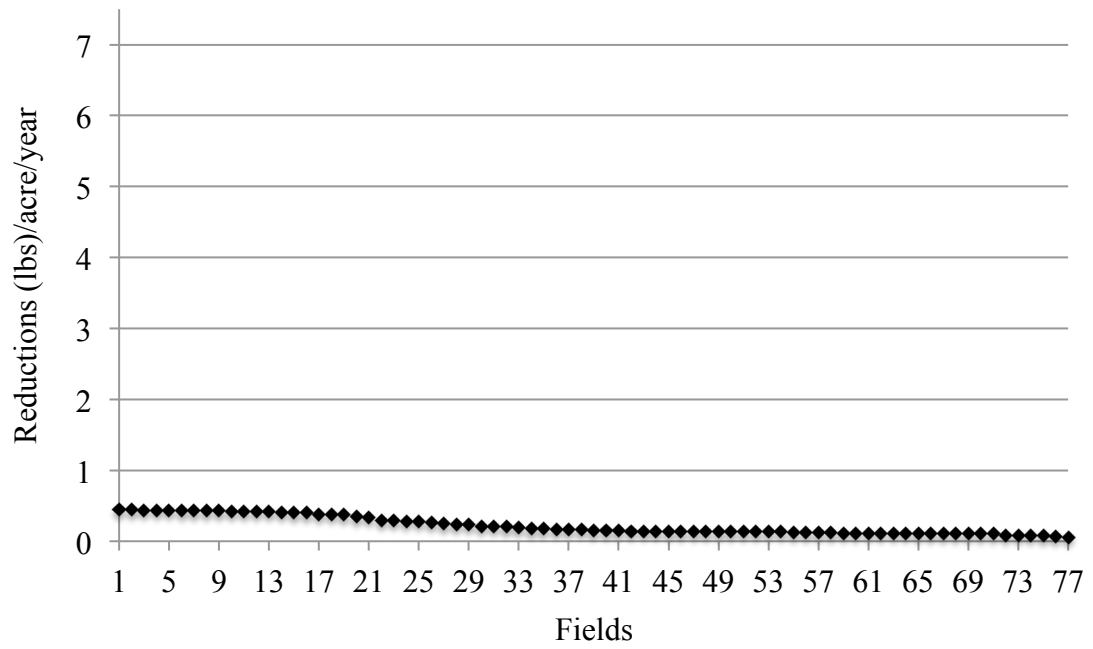
**Table 3** Predicted Participation of Low-load Fields with Various Subsidies and/or Bonuses

Subsidy Level and/or Bonus (per acre)	Participation % by best management practices			
	Decision Agriculture	Forest Buffer	Grass Buffer	Land Use Conversion
\$0	0%	94.8%	94.8%	2.6%
\$10	0%	96.1%	96.1%	5.19%
\$50	100%	98.7%	100%	28.6%
\$100	100%	100%	100%	49.4%

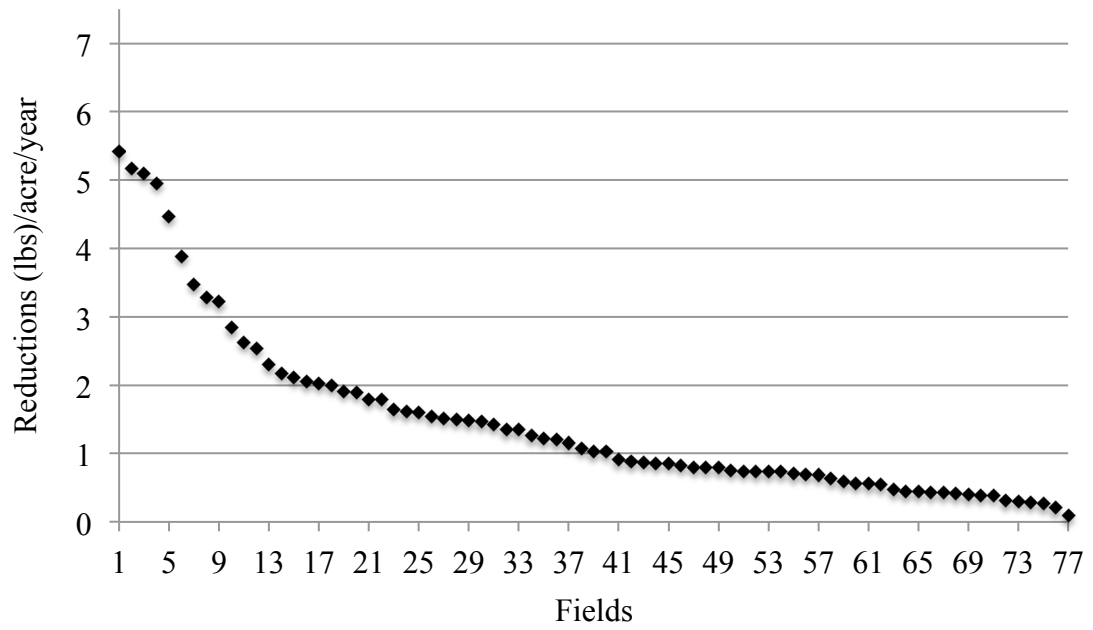
Notes: Participation rates assume an average of the high and low costs for each field and the average of the high and low credit price predicted for each field. All heterogeneity comes from the benefits side. Subsidies of \$10, \$50, and \$100 per acre of BMP were applied to each of the 4 BMPs. The expected participation rates were determined after the subsidies were applied.



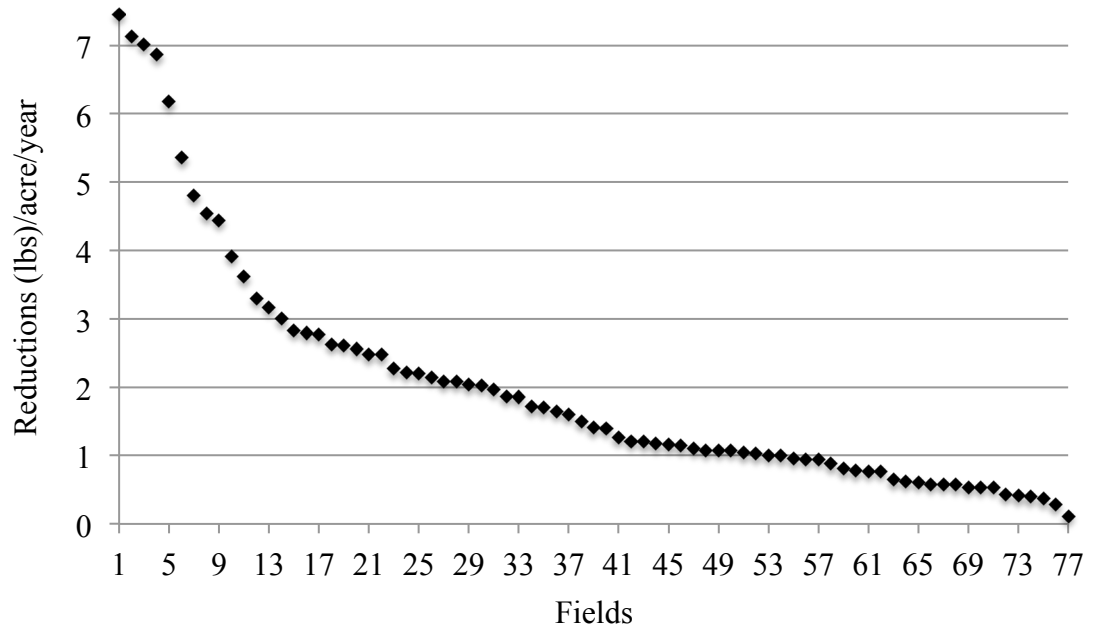
**Figure 1. Diagram of offset and BMP markets.** The diagram on the left represents the ecosystem services offset market where the supply of nutrient offsets comes from nonpoint sources of pollution, and demand for offsets is from point sources of pollution. The diagram on the right represents the market for farmer’s demand for BMPs. The demand for BMPs is derived from the offsets supplied in the offset market.



**Figure 2. Nitrogen reductions per acre for decision agriculture scenario.** Measured in pounds/acre for the 77 sampled fields, under the 4 BMP scenarios.

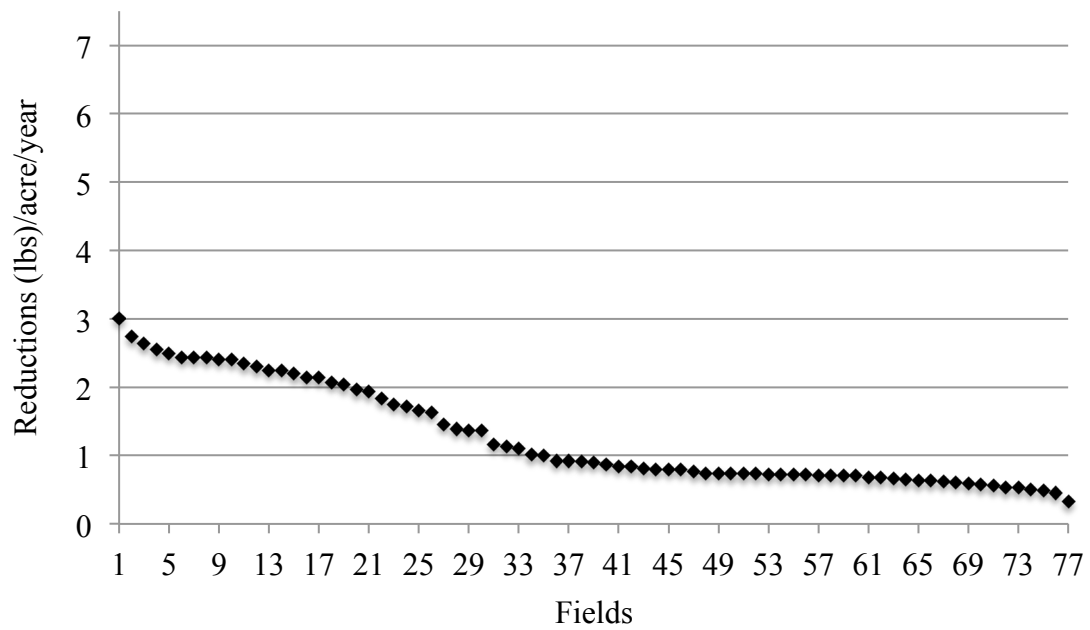


**Figure 3. Nitrogen reductions per acre for grass buffer scenario.** Measured in pounds/acre for the 77 sampled fields, under the 4 BMP scenarios.

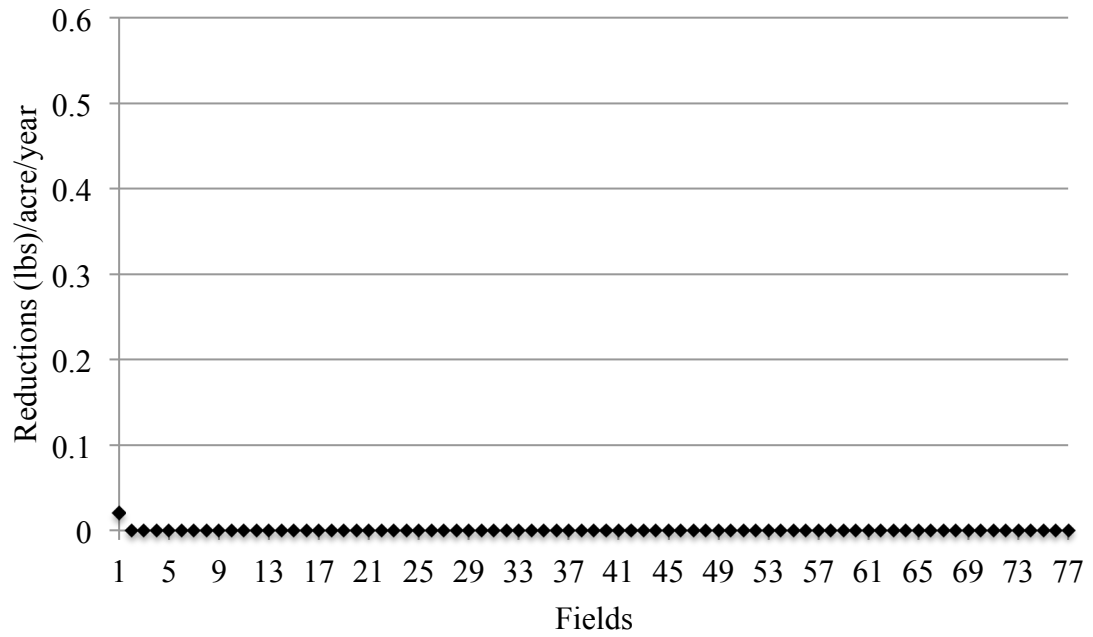


**Figure 4. Nitrogen reductions per acre for forest buffer scenario.** Measured in pounds/acre for the 77 sampled fields, under the 4 BMP scenarios.

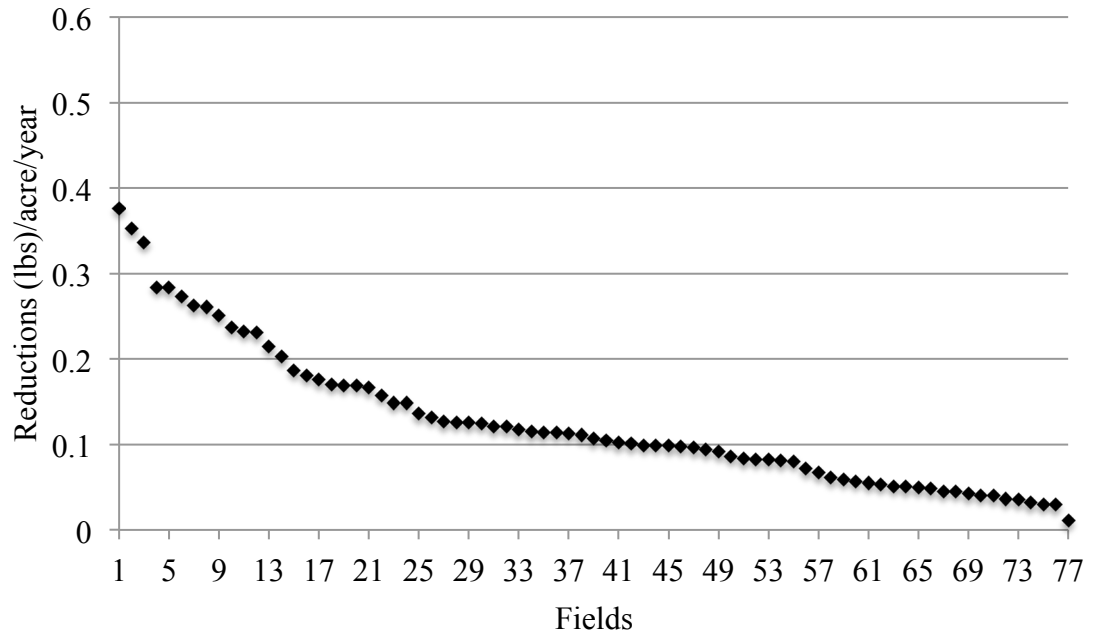




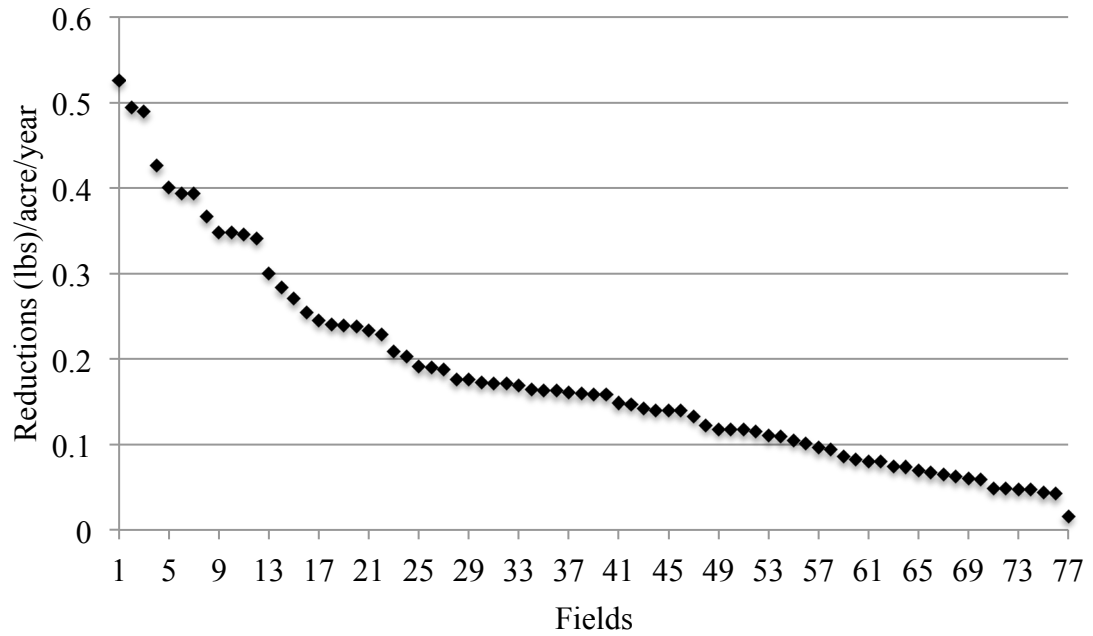
**Figure 5. Nitrogen reductions per acre for land use conversion scenario.** Measured in pounds/acre for the 77 sampled fields, under the 4 BMP scenarios.



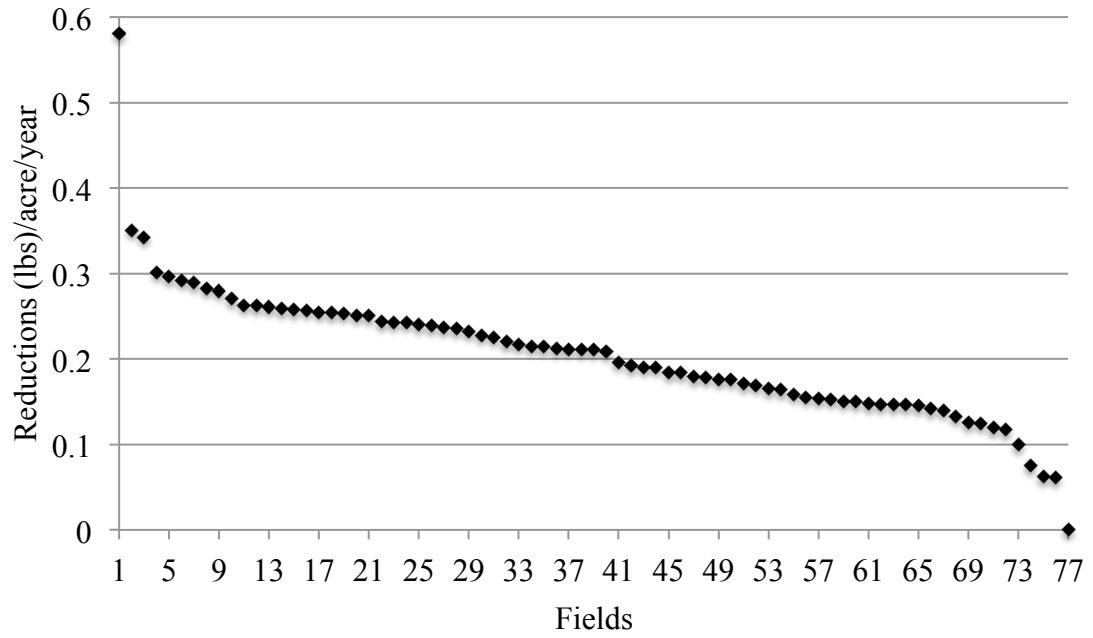
**Figure 6. Phosphorus reductions per acre for decision agriculture scenario.** Measured in pounds/acre for the 77 sampled fields, under the 4 BMP Scenarios. The only reduction found under decision agriculture is an error within MDNTT’s calculations since there is no phosphorus efficiency for decision agriculture.



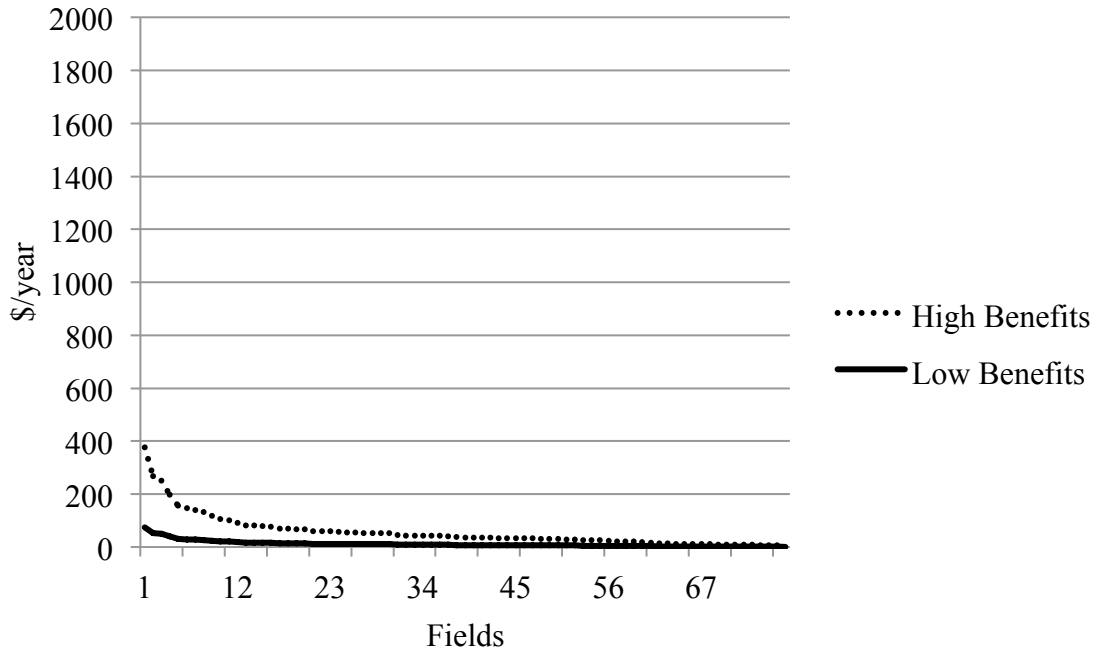
**Figure 7. Phosphorus reductions per acre for grass buffer scenario.** Measured in pounds/acre for the 77 sampled fields, under the 4 BMP Scenarios.



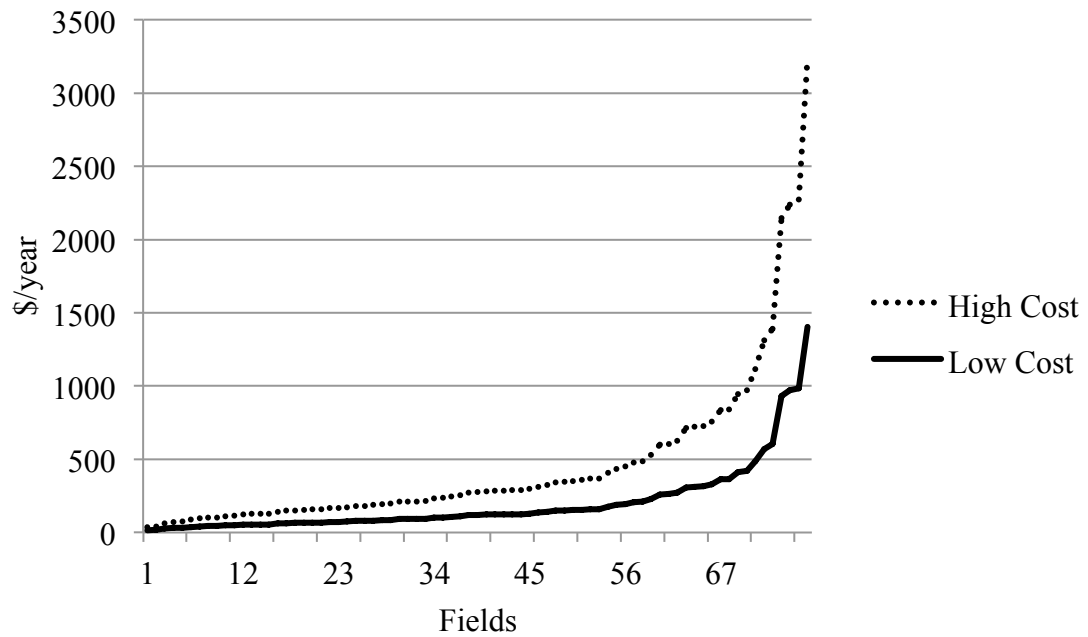
**Figure 8. Phosphorus reductions per acre for forest buffer scenario.** Measured in pounds/acre for the 77 sampled fields, under the 4 BMP Scenarios.



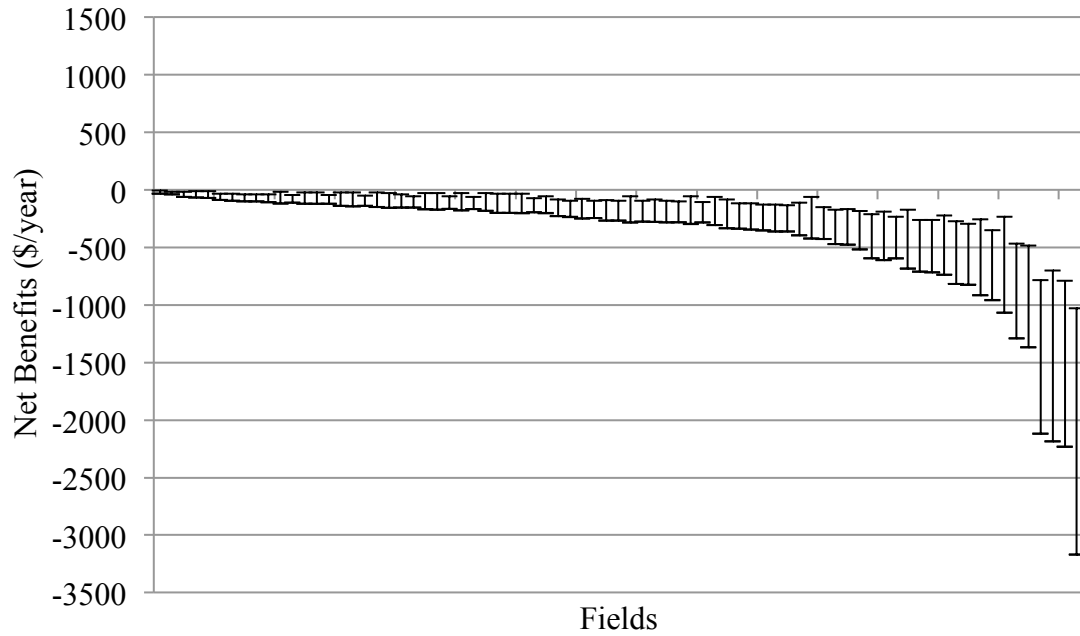
**Figure 9. Phosphorus reductions per acre for land use conversion scenario.** Measured in pounds/acre for the 77 sampled fields, under the 4 BMP Scenarios.



**Figure 10. Derived benefits figures for decision agriculture scenario.** The 77 sample fields were organized from highest to lowest benefits, and therefore may not correspond with the same field number from the cost estimate figure. Benefits are the total benefits for the entire field generated from implementation of the practice across the entire field.

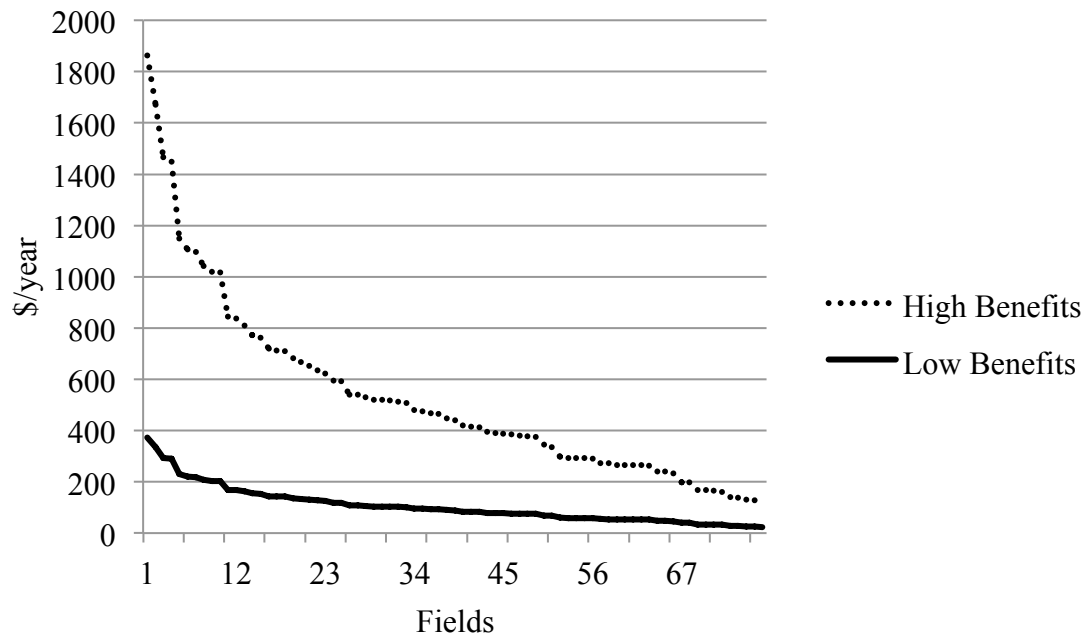


**Figure 11. Cost figures for decision agriculture scenario.** Cost estimates were obtained from Chesapeake Bay Commission Economic Study (2012). The 77 sampled fields estimates were organized from lowest to highest values, and therefore may not correspond with the same field number from the cost estimate figure. Costs are the total cost of applying the practice to the entire field.

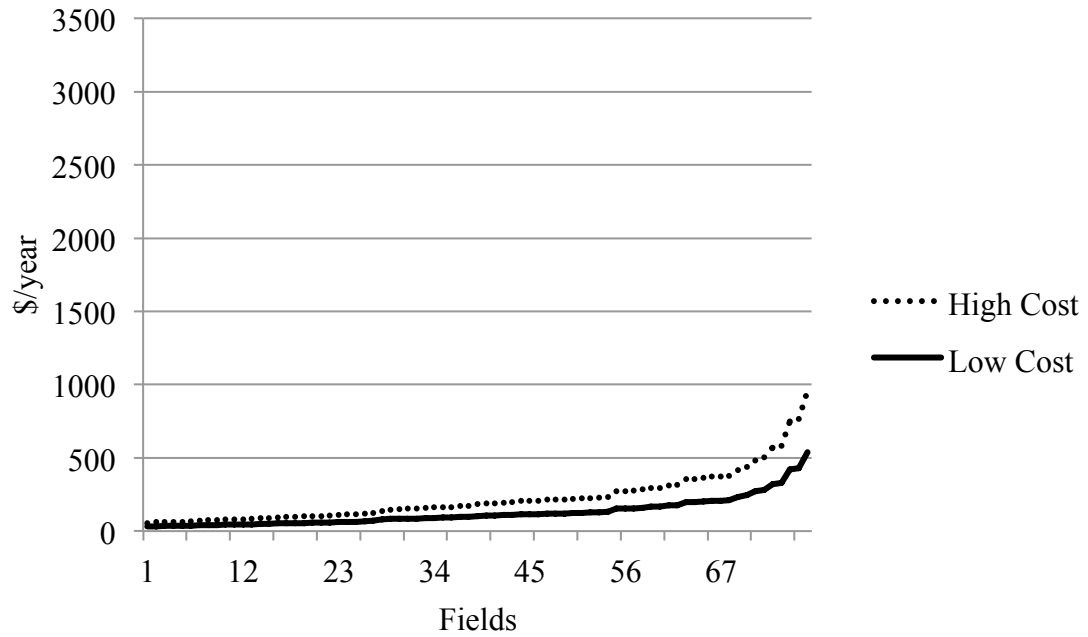


**Figure 12. Net benefits for decision agriculture scenario.** Indicates the difference between net benefits at the high credit price and low cost level (upper horizontal bar), and net benefits at the low credit price and high cost level (lower horizontal bar). Values were calculated by subtracting expected costs of implementation from expected benefits.

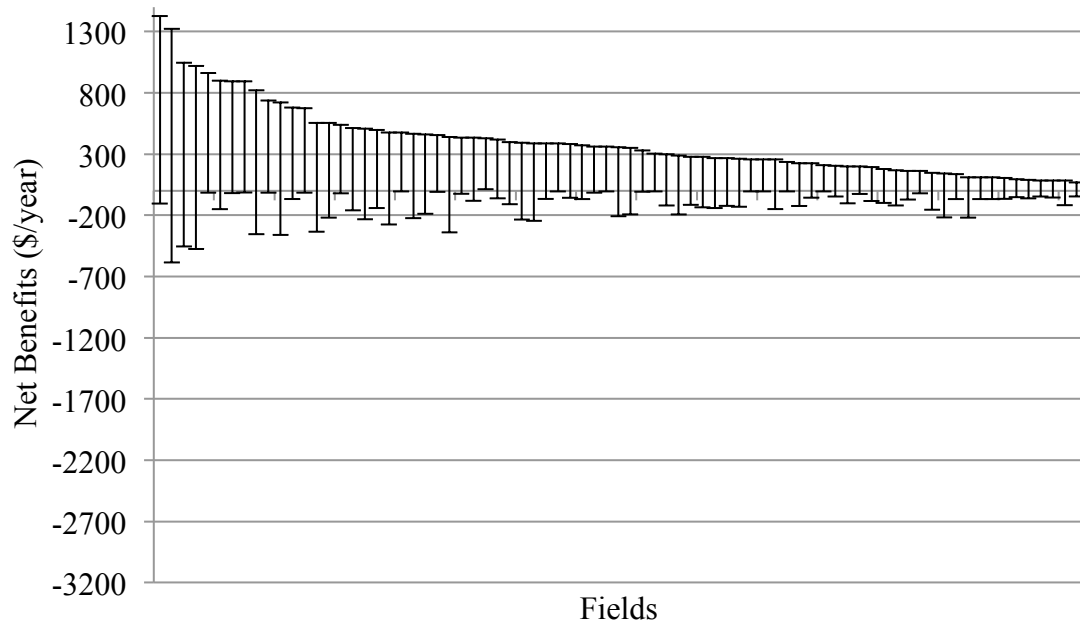




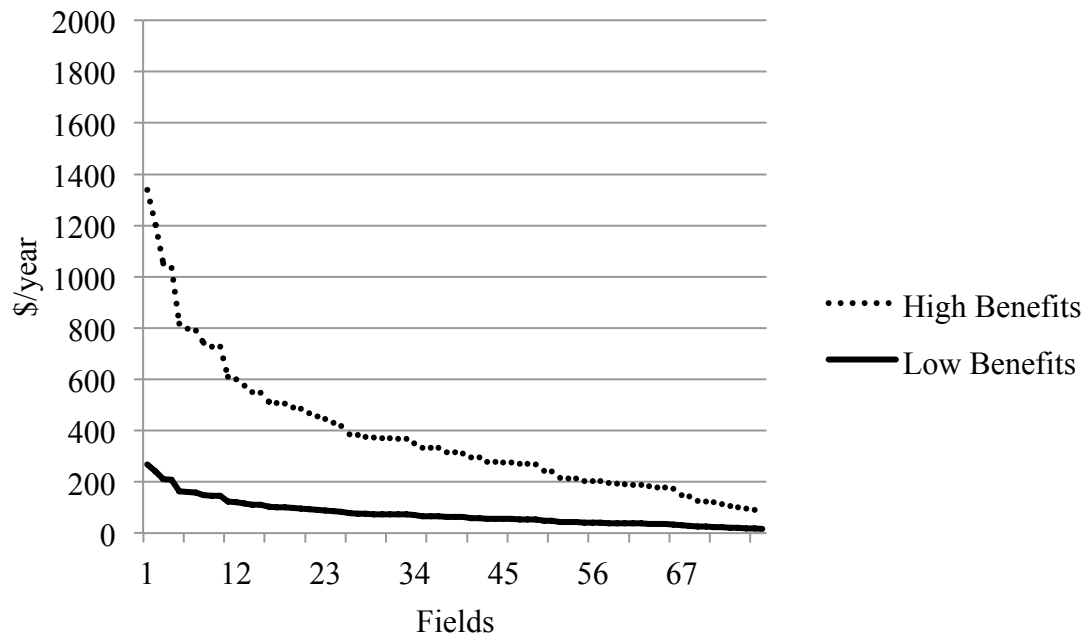
**Figure 13: Derived benefits for forest buffer scenario.** The 77 sample fields were organized from highest to lowest benefits, and therefore may not correspond with the same field number from the cost estimate figure. Benefits are the total benefits for the entire field generated from implementation of the practice on an estimated buffer size.



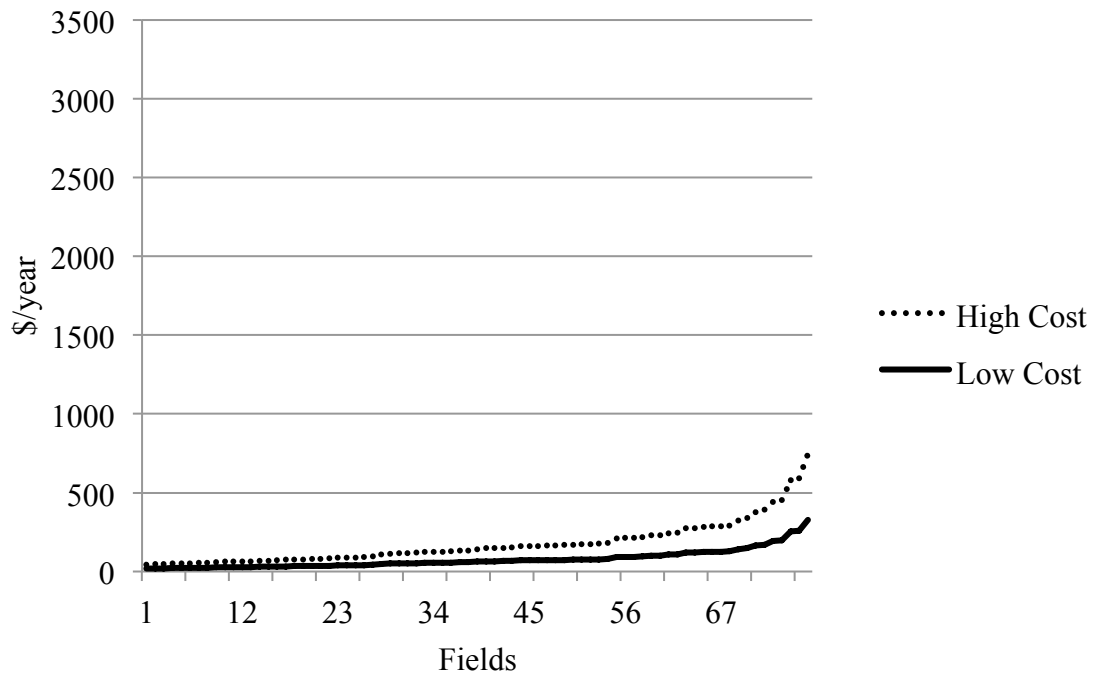
**Figure 14. Cost figures for forest buffer scenario.** Cost estimates were obtained from Wainger et al. (forthcoming). Costs were applied to an estimated buffer size for each of the 77 fields and represent the entire cost of implementation. Estimates were organized from lowest to highest values, and therefore may not correspond with the same field number from the cost estimate figure. Forest buffer and grass buffer cost curves are scalar transformations due to use of same buffer acreage with different costs.



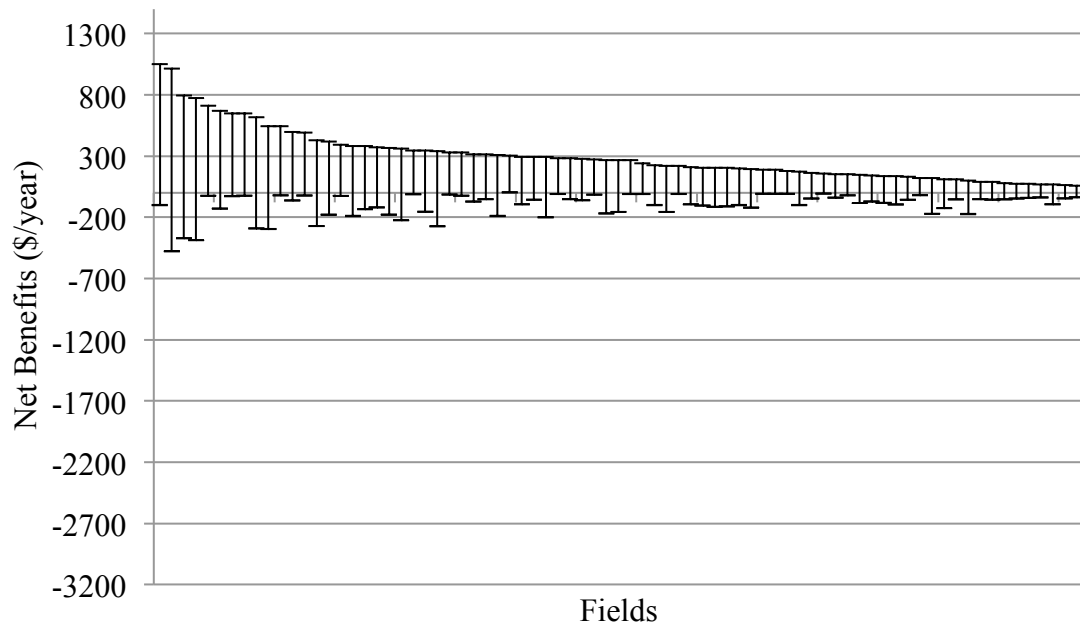
**Figure 15. Net benefits for forest buffer scenario.** Indicates the difference between net benefits at the high credit price and low cost level (upper horizontal bar), and net benefits at the low credit price and high cost level (lower horizontal bar). Values were calculated by subtracting expected costs of implementation from expected benefits.



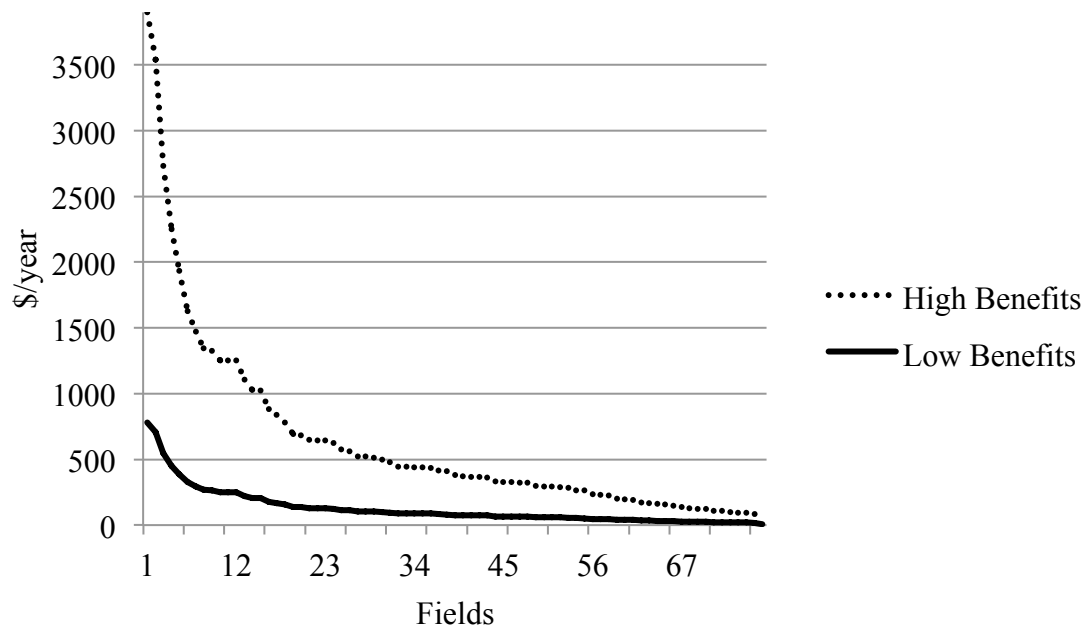
**Figure 16. Derived benefits for grass buffer scenario.** The 77 sample fields were organized from highest to lowest benefits, and therefore may not correspond with the same field number from the cost estimate figure. Benefits are the total benefits for the entire field generated from implementation of the practice on an estimated buffer size.



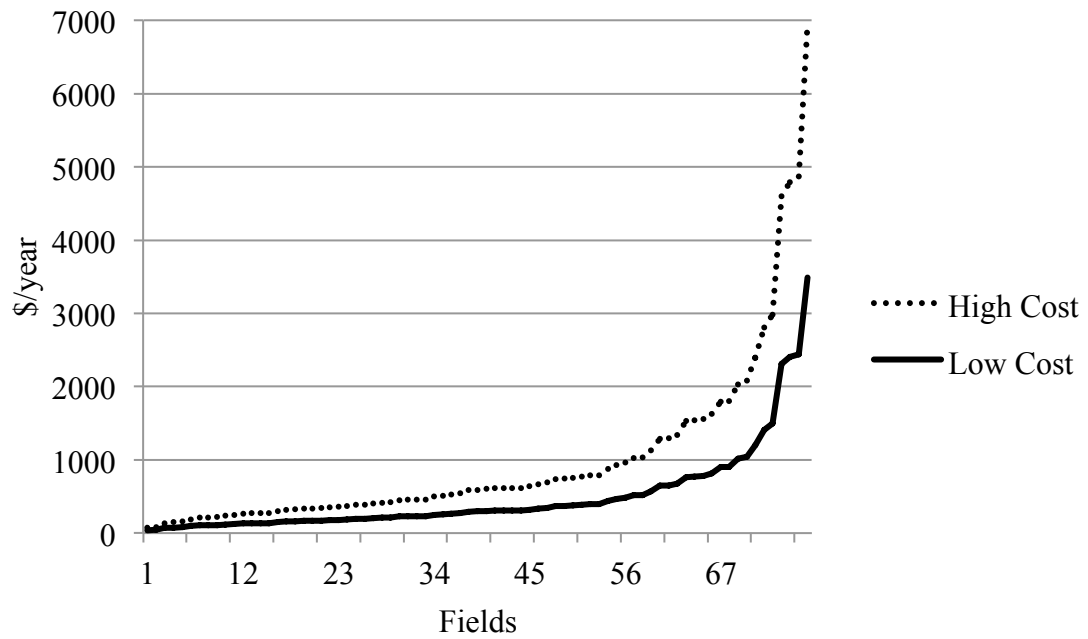
**Figure 17. Cost figures for grass buffer scenario.** Cost estimates were obtained from Wainger et al. (forthcoming). Costs were applied to an estimated buffer size for each of the 77 fields and represent the entire cost of implementation. Estimates were organized from lowest to highest values, and therefore may not correspond with the same field number from the cost estimate figure. Forest buffer and grass buffer cost curves are scalar transformations due to use of same buffer acreage with different costs.



**Figure 18. Net benefits for grass buffer scenario.** Indicates the difference between net benefits at the high credit price and low cost level (upper horizontal bar), and net benefits at the low credit price and high cost level (lower horizontal bar). Values were calculated by subtracting expected costs of implementation from expected benefits.

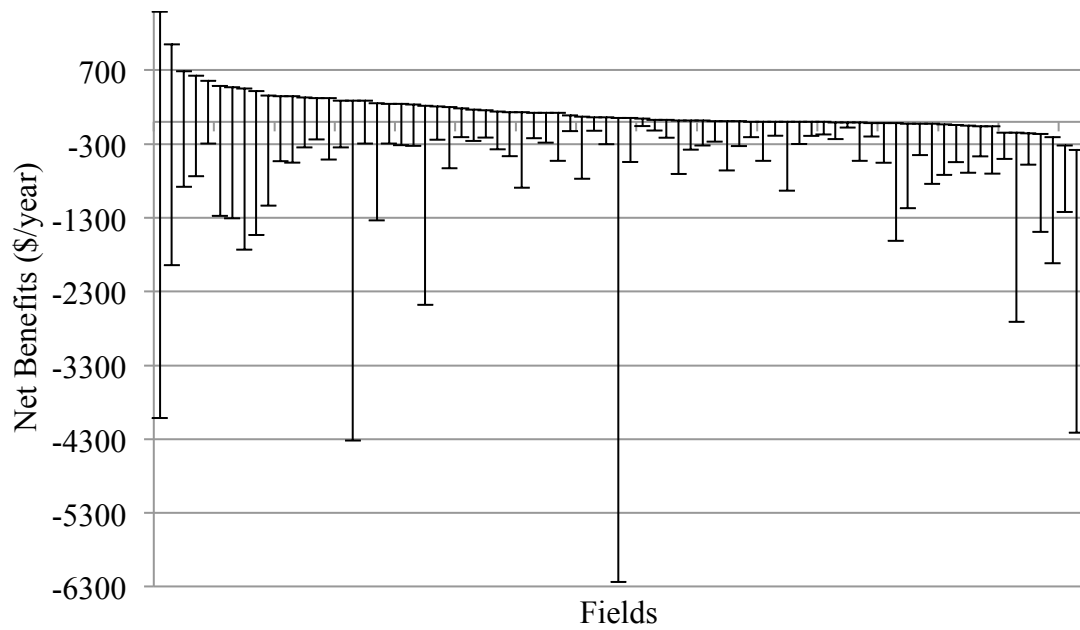


**Figure 19. Derived benefits for land use conversion scenario.** The 77 sampled fields were organized from highest to lowest benefits, and therefore may not correspond with the same field number from the cost estimate figure. Benefits are the total benefits for the entire field from the retiring of 25% of field acreage to forest.



**Figure 20. Cost figures for land use conversion scenario.** Cost estimates were obtained from Wainger et al. (forthcoming), and applied to the size of the retired land for the 77 sampled fields. Estimates were organized from lowest to highest values, and therefore may not correspond with the same field number from the cost estimate figure.





**Figure 21. Net benefits for the land use conversion scenario.** Indicates the difference between net benefits at the high credit price and low cost level, and net benefits at the low credit price and high cost level. Values were calculated by subtracting expected costs of implementation from expected benefits.

## Appendix

### ASSUMPTIONS USED TO AUGMENT AND RECONCILE SURVEY DATA IN NUTRIENT NET

Agronomic Factor	Assumption(s) Made
Planting Method	If no-till is used, assumed no-till drill as the planting method
Soil P Test Values	If a value was missing, assumed value to be 150 FIV All units measured in FIV All values tested at UMD Lab for Ag and Environmental Science
Planting Date	Corn (grain, sweet, and silage): 5/1. Soybeans: 5/1 or 7/1
Harvest Date	All harvested on 9/15
Commercial Fertilizer Application Date	Corn 4/15. Soybeans 5/1
Commercial Fertilizer Incorporation Depth	2 inches
Manure Type	If poultry manure used, assumed

	to be broiler chickens
Manure Application Date	3/15, 2/15, or 5/1
Manure Consistency	If poultry, assumed solid. If milk cow, assumed liquid
Manure Nitrogen Concentration	Poultry: 73 lbs/ton. Milk Cows: 5.95 lbs/ton
Manure Phosphorus Type	Measured in P2O5
Poultry Manure	Assumed phytase and poultry litter treatment
Manure Incorporation Depth	4 inches
Manure Moisture Content	Broiler Chickens: 27.48%. Milk Cows: 94.02%
If Land Use Conversion BMP	Assumed 25% of field converted to forest

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Source Notes: Table was originally produced in Duke, et al. (2012).

