AN ECONOMIC ANALYSIS OF THE POTENTIAL 'VOLUNTARY' REDUCTIONS OF NUTRIENTS FROM AGRICULTURE TO THE CHESAPEAKE BAY FROM THE SHENANDOAH SOIL AND WATER CONSERVATION DISTRICT, VIRGINIA

by

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An Economic Analysis of the Potential ‘Voluntary’ Reductions of Nutrients from Agriculture to the Chesapeake Bay from the Shenandoah Soil and Water Conservation District, Virginia

A Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at George Mason University

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ABSTRACT

AN ECONOMIC ANALYSIS OF THE POTENTIAL 'VOLUNTARY' REDUCTIONS OF NUTRIENTS FROM AGRICULTURE TO THE CHESAPEAKE BAY FROM THE SHENANDOAH SOIL AND WATER CONSERVATION DISTRICT, VIRGINIA

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This study addresses the lack of an in-depth assessment of field-level costs for implementing agricultural best management practices (BMPs). An economic analysis of the potential contribution of 'voluntary' reductions of nutrients from agricultural non-point sources of pollution to the Chesapeake Bay originating in the Shenandoah Soil and Water Conservation District (Shenandoah SWCD), Virginia was conducted. The research had three high level objectives: 1) to assess the heterogeneity in costs of implementing BMPs at the field-level; 2) to estimate the magnitude of potential nutrient reductions possible from agriculture in the Shenandoah SWCD, Virginia based on the field-level cost analysis and Virginia's trading program statutory requirements, *ceteris paribus*; and 3) to evaluate alternative scenarios of nutrient reduction based on the sensitivity of farmers to credit prices and allowable BMPs. The study considers the economic and physical factors associated with farms and builds on a vast base of literature on the physical aspects of non-point source pollution abatement.

The heterogeneity in costs of six BMPs applied in the Shenandoah SWCD over six years is analyzed. There is significant heterogeneity in field-level costs with the coefficient of variation ranging from 19 to 72 percent. The median cost for BMPs is found to be similar to the average cost used in other studies for evaluating nutrient credit markets. Therefore, fifty percent of the time implementation costs exceed the average and farmers with those prospects are not be likely to participate in the market.

An analysis of the nutrient contributions from Shenandoah SWCD agriculture found that under current fixed nutrient prices, for those farmers that have installed baseline BMPs, an expected 12,960 pounds of nitrogen and 2,130 pounds of phosphorus would be reduced annually from trading. If all farms were to meet the baseline, as many as 632,220 pounds of nitrogen and 41,372 pounds of phosphorus are reduced in a given year. This represents from 0.5 to 22 percent of the current nitrogen load and 0.2 to 4 percent of the current phosphorus load. An analysis of trading using a wastewater treatment facility cost of implementation based price yields an additional four percent in nitrogen reduction and six percent in phosphorus reduction over the fixed price scenario. A third analysis using a stormwater management BMP implementation cost based credit price yields a 15 percent reduction in nitrogen and six percent reduction in phosphorus over the fixed price scenario. By not considering the heterogeneity in costs, previous economic assessments have greatly overestimated trading potential which is consistent with a lack of actual trading in the market.

CHAPTER ONE: INTRODUCTION

In the United States, the EPA (2009) reports that nutrient pollution is the fifth highest cause for impaired estuaries and is having devastating ecological impacts. Both point- (e.g., wastewater treatment facilities) and non-point sources of nutrients are contributing to water quality impairments with agriculture being the number one source (EPA, 2009). While point sources are regulated under the Clean Water Act, with the exception of confined animal feedlots, agricultural runoff of nitrogen and phosphorus is not regulated.[1] Reducing agricultural nutrient loads relies on "voluntary efforts." Policy mechanisms to encourage the voluntary adoption of agricultural best management practices (BMPs) to reduce runoff include payments for environmental services and market-based nutrient trading (Fu et al., 2012).

Nutrient trading between point- and non-point sources has the potential to deliver significant cost savings and provide economic efficiencies (Anderson et al., 1997; Faeth, 2000; Horan et al., 2001). Wastewater treatment facilities have a high cost to reduce nutrient pollution relative to agricultural producers whose costs are considered relatively "low cost" (Butt and Brown, 2000; Faeth, 2000; Ribaudo et al., 2005; Senate Finance Committee, 2011). Additionally, nutrient trading delivers ancillary ecological benefits such as restoration of habitat, carbon sequestration, and reduced erosion (EPRI, 2012).

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1. Confined animal feed lots and poultry operations are regulated under the Clean Water Act.

Water quality trading programs across the United States have had limited success in terms of market activity (Newburn and Woodward, 2012). One reason that success of nutrient credit markets has not been realized is that the markets are designed without enough information. There is generally a lack in understanding in the field-level costs of agricultural BMP implementation and this information would move the state of knowledge forward (Ribaudo, 2013). To address this lack of knowledge of field-level costs of agricultural BMPs a case study of the Shenandoah Soil and Water Conservation District (SWCD) of Virginia in the Chesapeake Bay watershed is conducted.

The Chesapeake Bay ("the Bay") is the largest estuary in the United States (Chesapeake Bay Foundation, 2011) and suffers from impaired water quality as result of nutrient pollution largely contributed by agriculture. A number of studies have estimated the economic potential of nutrient trading in the Bay watershed (e.g., CBC, 2012; Wainger et al., 2013; USDA, 2013 forthcoming); however none have included an assessment of BMP implementation costs at the field-level. This may have led to an over- or under-estimation of potential benefits of nutrient credit trading. An economic analysis of field-level costs to estimate the potential voluntary reductions of nutrients from agricultural non-point sources of pollution to the Bay is needed. This case study assesses the potential reduction of agricultural non-point source pollution from the Shenandoah SWCD of Virginia based on field-level costs and estimates the implications for nutrient credit trading.

Specifically, this study estimates agricultural producers' willingness to participate in a nutrient credit trading program in order to address three objectives:

1) to assess the heterogeneity in costs of implementing and maintaining BMPs at the field-level;

2) to estimate the magnitude of nutrient reductions from agriculture in Shenandoah SWCD based on the field-level cost analysis and Virginia's trading program statutory requirements, *ceteris paribus*; and

3) to evaluate alternative scenarios of nutrient reduction based on the sensitivity of farmers to credit prices and allowable BMPs.

Ecological impacts of nutrient pollution, sources of nutrients, and background information on the Bay are subjects of the first chapter. Chapter Two will delve into the current state of knowledge of agricultural BMP effectiveness, implementation costs, other factors associated with farmer willingness to provide nutrient pollution credits, the economic basis for nutrient trading, and previous evaluations of nutrient market potential. Chapter Three describes the approach, data, and results of an analysis of heterogeneity in field-level costs in the Shenandoah SWCD. Chapter Four describes the approach, data, and provides results of an estimation of potential nutrient pollution reduction from agriculture in the Shenandoah SWCD, *ceteris paribus* including sensitivity analysis with various credit price options. The implications of the analysis for the Commonwealth of Virginia's overall nutrient trading program will also be described in this chapter. Chapter Five will describe the potential magnitude of trading if Virginia were to revise its trading regulations, discuss the relevance of this research to the broader policy questions, describe how this analysis contributes to scholarship in this field, and identify areas for further research.

Ecological Impacts of Nutrients

Nutrients are critical in estuarine environments for the development of organisms such as the staple food item phytoplankton. However, under conditions of very high concentrations, nitrogen is toxic in drinking water (10 mg/liter) and dissolved ammonia is very toxic to fish (Mesner and Geiger, 2010). High, but not toxic, inputs of nutrients are also harmful and may have cascading impacts when resulting in aquatic eutrophication. Eutrophication is “the natural or artificial addition of nutrients to bodies of water and …when the effects are undesirable, eutrophication may be considered a form of pollution” (National Academy of Sciences, 1969). In fact, eutrophication is regarded as one of the preeminent threats to coastal ecosystem health (CENR, 2000; NRC, 2000).

The nutrients that enter estuaries from the watershed increase nutrient concentration above the “pre-introduction” equilibrium. Higher levels of nutrients increase phytoplankton production and biomass which in turn reduces the light availability in the water and increases sedimentation of organic matter. The new conditions of lower light availability reduce the ability for submerged aquatic vegetation to be productive and deliver oxygen to the water column (Bowen and Valiela, 2001). The increase in organic matter decomposition reduces oxygen levels leading to anoxic conditions (Bricker et al., 1999, 2007). The cascading effect of reduced light, oxygen, and habitat leads to changes in the zooplankton species composition, macrozoobenthos, and fish populations (Bowen and Valiela, 2001; Breitburg, 2002; Wazniak and Glibert, 2004; Andersen, 2006).

The ecological impacts of nutrient enrichment have been well studied in the United States. With an increasing concern about eutrophication in the 1990’s, the

National Oceanic and Atmospheric Administration (NOAA) conducted the first survey of the Nation's estuaries to assess the extent and impacts of eutrophication (Bricker et al., 1999). An update of the survey was completed in 2007 (Bricker et al., 2007). Both surveys found that the majority of estuaries assessed were suffering from nutrient pollution related impacts.

Sources of Nutrient Pollution

There are two major categories of nutrient pollution: point source (e.g., pollution delivered via a "pipe" such as that created by wastewater treatment plants) and non-point source (i.e., dispersed pollution from sources including agriculture, urban stormwater, and air deposition). Analyses indicate that non-point sources contribute approximately 81 percent of the nitrogen that reaches the Bay and 84 percent of the phosphorus, with agricultural runoff identified as the largest single polluter (CBPO, 2013b). Figure One depicts the share of nutrient pollution contributed by each of the major sources.

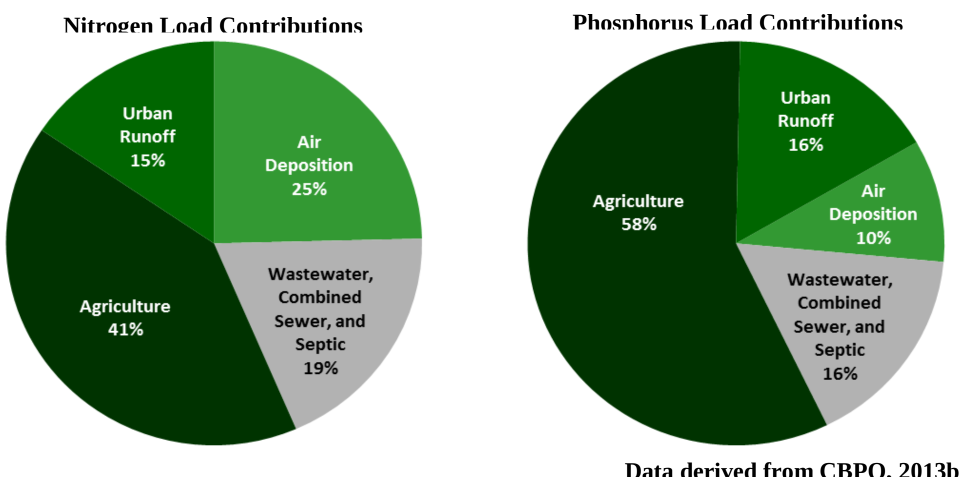


Figure 1. Sources of Nutrient Pollution to the Bay (Data Derived from CBPO, 2013b)

Agricultural practices use nutrients as inputs in the production process, applied as components of fertilizers. Nutrients are also introduced in animal waste, both as fertilizer and as a byproduct of livestock. Nutrients not taken up by plants can be transported from the surface via runoff or through the ground via throughflow and ultimately end up in streams, creeks, rivers, and other bodies of water. Farm practices influence the amount of nutrients that enters waterways (EPA, 2005).

Chesapeake Bay Background

The Bay is the largest estuary in the United States with a watershed area of 102,998,000 square linear meters (64,000 square miles), making it a significant and unique natural resource (Chesapeake Bay Foundation, 2011). It is ecologically rich, supporting diverse flora and fauna, and is also an important economic asset, providing fisheries income, revenue-generating recreational activities, and numerous ecosystem services. The Bay suffers from water quality issues largely due to high loads of nutrients (nitrogen and phosphorus) and sediment (CBPO, 2012). For over thirty years, scientists, researchers, and policy-makers have been working to improve water quality in the Bay. However, efforts to date have not been entirely successful. The Bay's watershed is home to approximately 17 million people and is fed by more than 100,000 streams, creeks, and rivers (Chesapeake Bay Foundation, 2011).

The Clean Water Act (33 U.S.C. §1251 et seq. (1972)) is the regulatory authority by which the Environmental Protection Agency (EPA) can set limits on the quantities of pollutants discharged into the Nation's surface waters, including nutrient pollution. On December 29, 2010, the EPA established the Chesapeake Bay Total Maximum Daily

Load (TMDL), a historic and comprehensive “pollution diet” for the Bay (EPA, 2011). The TMDL establishes a limit on nutrient pollution loads in the Bay and its tidal rivers. The loads are associated with desired water quality standards. Specifically, the TMDL set Bay watershed annual limits of:

- 185.9 million pounds of nitrogen; a 25% reduction from current loads,
- 12.5 million pounds of phosphorus; a 24% reduction,
- 6.45 billion pounds of sediment per year; a 20% reduction (EPA, 2010).

The EPA does not prescribe how regulated parties must achieve these reductions. Rather, the TMDL allocates the limits across 92 land-river segments within the watershed and each state is responsible for developing Watershed Implementation Plans (WIP) on their approach to meeting their share of pollution reduction.

Virginia contributes nutrient pollution to 39 of the TMDL land-river segments, all of which are listed as impaired for excessive nutrients and sediments (Commonwealth of Virginia, 2010). Virginia agriculture is estimated to contribute 23.6 million pounds of nitrogen and 6 million pounds of phosphorus to the Bay.[2] Virginia’s total load allocation for 2025 based on the TMDL is 53.4 million pounds of nitrogen; 29 percent of the total Chesapeake Bay allocation for nitrogen. Of this, the agricultural sector is allocated 16.4 million pounds of nitrogen. Virginia’s total allocation for phosphorus is 5.4 million pounds; 43 percent of the total Chesapeake Bay allocation. The agricultural sector is allocated 2.1 million pounds of phosphorus in Virginia. (Commonwealth of Virginia,

2. Based on a model run of the Chesapeake Assessment Scenario Tool using 2013 initial conditions (latest available) for the State of Virginia.

2010). This will require that Virginia agriculture reduce 7.2 million pounds of nitrogen and 3.9 million pounds of phosphorus.

The Bay TMDL is designed to bring nutrient concentrations in the Bay in line with state water quality standards (i.e., the Bay will be fishable and swimmable). Specifically, the TMDL load reduction targets will meet quality standards for dissolved oxygen, water clarity, underwater Bay grasses, and *chlorophyll a*, an indicator of algae levels (EPA and CBPO, 2010). These ecological quality standards will restore ecosystem services such as fishing, recreation, and aesthetics.

Shenandoah Soil and Water Conservation District Background

The Commonwealth of Virginia has over 47,000 farms with an average size of 171 acres (USDA, 2007). Thirty-three percent of Virginia's land is agricultural land (VDACS, 2014). The Shenandoah Valley is a major agricultural producer for the Commonwealth of Virginia with four of the top five agricultural producing counties (USDA, 2007). Nearly fifty percent of the land use in the Shenandoah Valley is agricultural due to the rich, productive soils (Northern Shenandoah Valley Regional Commission, 2012).

The Shenandoah SWCD is representative of Virginia agricultural industry. The district includes Page and Rockingham Counties and the City of Harrisonburg (Shenandoah SWCD, 2014b). Page County has 530 farms that average in size at 121 acres and Rockingham County has 1,970 farms that average in size at 118 acres (USDA, 2007); similar to the statewide average. The highest proportion of earnings from agriculture in Virginia is livestock (70 percent); Page and Rockingham counties earn more than 90 percent of agricultural income from livestock (USDA, 2007). The Shenandoah SWCD is also representative with the same top commodities as Virginia: forage (hay) has the highest land use proportion of all crops and broilers and turkeys make up the greatest proportion of livestock in both counties as well as the state overall.

The Shenandoah River (both North and South Forks) drains most of the Shenandoah Valley and is the primary water source through the Shenandoah SWCD to the Chesapeake Bay (Northern Shenandoah Valley Regional Commission, 2012).

It is estimated that Shenandoah SWCD is currently contributing 2.8 million pounds of nitrogen and 1.1 million pounds of phosphorus.[3] If load reductions for agriculture are proportionate to current loads, the Shenandoah SWCD will have to reduce 0.85 million pounds of nitrogen and 385,000 pounds of phosphorus.

Agricultural Best Management Practices

Since agriculture is the largest contributor of non-point source pollution, steps to reduce the use and manage fertilizer are important in reducing the concentration of nutrients in the Bay. There are a number of methods to achieve this, known as best management practices (BMP). These include: nutrient management planning, planting buffer zones, planting cover crops, increasing woodlands, and controlling manure. Implementation of BMPs is a key component of state WIPs to meet the TMDL goals.

Each of these BMPs will have costs including installation and maintenance costs. The BMPs also have benefits measured as effectiveness in reducing nutrient runoff. The

3. Based on a model run of the Chesapeake Assessment Scenario Tool using 2013 initial conditions (latest available) for the Shenandoah SWCD.

cost and benefit considerations affect which of the BMPs should be employed and also where they will have the best benefit-to-cost ratio. The costs and benefits will vary from state to state, farm to farm, and even field to field within a farm. Chapter Two will include detailed discussion of the types of BMPs, their relative effectiveness, and associated costs.

Nutrient Credit Trading

The majority of nutrient contributions is from non-point sources and is largely unregulated. Wastewater treatment facilities are regulated and have greatly reduced nutrient loads in current operations. Each facility is subject to a compensatory allocation cap; i.e., the quantity prescribed in their nutrient pollution discharge permit in accordance with the Clean Water Act. Additional reductions or the increase in capacity at current or new plants will be very costly to offset (Senate Finance Committee, 2011). The cost, however, of achieving reductions in nitrogen and phosphorus in the Bay via agricultural BMPs are less than implementing further reductions at wastewater treatment plants. Figure Two shows a comparison of costs to reduce a pound of nitrogen from various sources in the Chesapeake Bay watershed. According to the Chesapeake Bay Commission study (2012), a market-based system with trading of nutrient credits among parties will provide desired ecological outcomes at the lowest cost by providing the most efficient allocation of nutrient reductions.

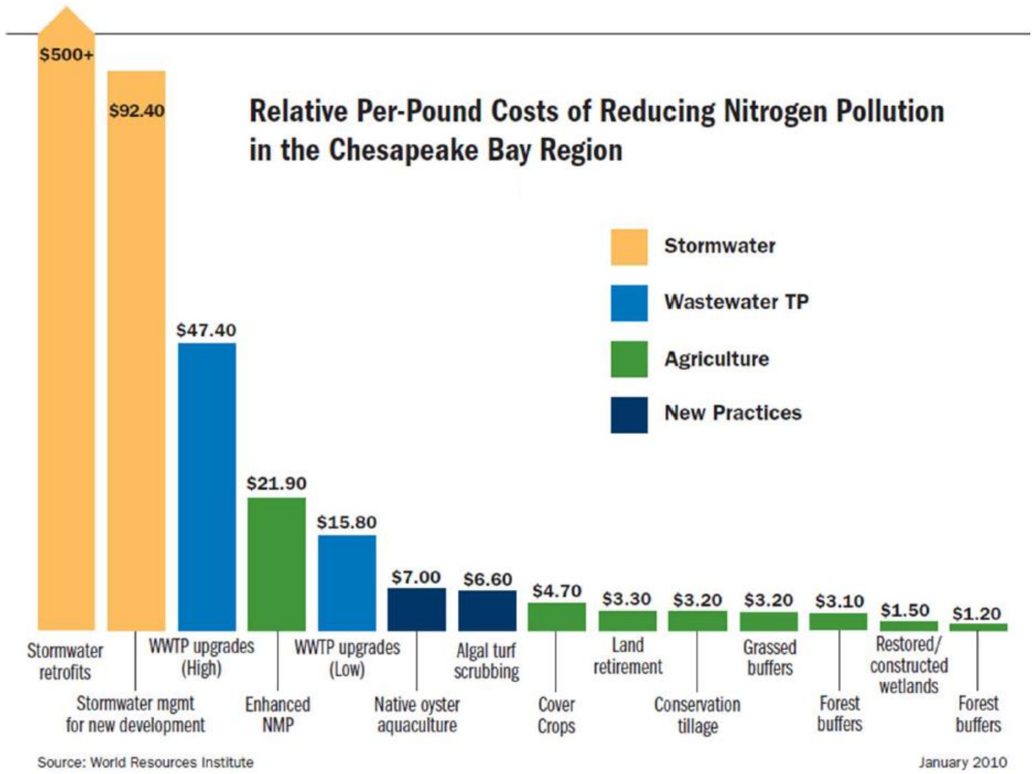


Figure 2. Comparison of Source Costs of Nitrogen Reduction (Source: Senate Finance Committee, 2011)

In Virginia, the General Assembly provided the regulatory capacity for a market-based nutrient credit trading program to "assist in (a) meeting … cap load allocations cost-effectively and as soon as possible in keeping with the 2010 timeline and objectives of the Chesapeake 2000 Agreement, (b) accommodating continued growth and economic development in the Chesapeake Bay watershed, and (c) providing a foundation for establishing market-based incentives to help achieve the Chesapeake Bay Program's non-point source reduction goals" in 2005 (Virginia General Assembly, 2005).

Nutrient market trading success relies on the heterogeneity in the cost of achieving nutrient reductions by different providers. Theoretically, if one provider can achieve a nutrient reduction at a lower cost they will be willing to sell a credit to the provider whom has a higher implementation cost. The price will achieve equilibrium above the actual implementation cost but below the cost that the provider with higher costs would incur to achieve the same nutrient reduction. Trading is a market mechanism that implements the given policy (the TMDL) through the least cost, thereby achieving the socially optimum solution from an economic perspective.

There are however, many complicating factors involved in a trading regime including the costs of BMP implementation at the field-level, additional factors that contribute to farmers' decision-making, the transaction costs associated with trading nutrient credits, and the capacity of individual farms to reduce nutrients in accordance with physical and regulatory constraints. There is a great deal of work that has been completed on the correlation between physical factors and the effectiveness of BMPs; there has been detailed cost analysis of point source pollution abatement costs; and there are evaluations of transaction costs and other factors that influence farmer decision-making. Missing from the literature is a detailed analysis of the field-level BMP implementation costs and how the heterogeneity in costs will affect the actual amount of nutrient pollution reduction that farmers are willing to provide on a 'voluntary' basis. The next chapter will explore BMPs, their effectiveness, costs, and markets in more detail.

CHAPTER TWO: STATE OF KNOWLEDGE

This chapter details the state of knowledge on agricultural BMP costs and nutrient credit trading in the Chesapeake Bay. It provides references to the significant literature on these topics. The current analysis builds largely upon what is already known about agricultural BMP effectiveness in reducing nutrient transport to the Bay, costs associated with the implementation of BMPs in the watershed, additional factors that influence farmers' willingness to participate in pay for environmental services programs, and nutrient trading.

This chapter will first describe the types of BMPs including a description of their function. This is followed by discussion of estimates of BMP efficacy in reducing nitrogen, phosphorus, or both. Findings from the literature on types of costs and average estimates for BMP implementation follows.

The factors that influence farmers' decisions to participate in cost-share programs will be described. Then the economic foundations for nutrient markets will be discussed. The rules for nutrient trading in Virginia will be described. Finally, the previous efforts to assess the potential of nutrient markets and gaps in the research will be detailed.

Description of Agriculture Best Management Practices (BMPs) for Nutrient Management

The agricultural BMPs for nutrient reduction in the scope of this research can be considered in seven major categories: nutrient management planning, buffer zones, cover crops, physical exclusions, tillage management, land conversion/conservation, and manure management. Each category addresses excess nutrients being exported from farms via a different part of the nutrient pathway, for instance at the point of introduction or the point of transport from the soil. There are 142 unique BMPs in the Chesapeake Bay Model (EPA, 2010a). The Virginia Department of Conservation and Recreation defines BMPs in the *Virginia Agricultural Cost Share Manual: Program Year 2015* (2014a). This analysis will be consistent with Virginia's definitions for specific practices, each of which falls into one of the seven high level categories. Table One provides a brief summary of each BMP type and the associated co-benefits.

Table 1. BMP Summary Descriptions

Category	BMP	Brief Description	Co-Benefits
Nutrient Management	Nutrient Management	Improved fertilization based on soil, crop, and other information	Reduced fertilizer cost
Buffer Zones	Grass	Area of vegetation at least 35 feet wide along water's edge	Streambank stabilization, wildlife habitat
	Forest		
	Wetland		
Exclusions	Offstream Watering (w/o fencing)	Excludes or reduces livestock stream access	Streambank stabilization, reduced fecal coliform pollution
	With Fencing		
Cover Crops	Cover Crops	Non-cash crop planted on field off-season	Reduced soil compaction, erosion, weeds
Tillage Management	Conservation Tillage	Reduced (minimum of 30% residue) or total elimination of tillage	Reduced fuel costs, reduced erosion, retains soil moisture
	No-Till		
Land Conversion/ Conservation	Land Conversion/ Conservation	Retires or preserves land as hay, pasture, or forest without any fertilizer application	Wildlife habitat, carbon sequestration
Manure Management	Phytase	Additive reduces P in excrement	Unknown
	Subsurface Injection	Injects liquid manure subsurface	Fertilizer is closer to crop roots

Nutrient Management Planning

Often farmers will overfertilize their crops because the cost of using additional fertilizer is outweighed by the risk of a reduced yield. Excess fertilization leads to nutrients not taken up by the crop which are then washed away and can end up in the Bay. Utilizing tools and information to fertilize at the optimal rate for crops is an important strategy to reducing the amount of nutrients input into the Bay. Nutrient management planning is based on advances in understanding of the biophysical nature of agroecosystems. The amount of nutrients that are needed and/or taken up by crops can vary on an annual basis due to both precipitation and solar radiance in a given year; additionally, individual farm factors such as soil nutrient balance, existence of legumes, and other crops can all affect the amount of nutrients that will be needed for the crop.

Generally, BMPs under the nutrient management planning classification can be described as "a management system that is information and technology based, is site specific and uses one or more of the following sources of data: soils, crops, nutrients, pests, moisture, or yield for optimum profitability, sustainability, and protection of the environment" (CAST, 2011). Farmers want to ensure that they are providing their crops with sufficient nutrients so that they will produce the greatest yield possible given their planted acreage. Given uncertainty in the amount of fertilizer needed, and the relatively low price, farmers are likely to apply more fertilizer than necessary to ensure that crops are not nutrient limited. The alternative carries a risk of reduced yield, which has a higher cost to farmers than over fertilizing under the current cost paradigm. It is important to note that the farmer's decision is currently based mainly on the direct costs of inputs (e.g., the price of fertilizer) and the direct benefits of crops (e.g., the price of corn). The ‘cost’ of the damage done by excess fertilizer is not inherent in the farmer’s decision. Nutrient management planning seeks to increase information available to the farmer to provide a more precise understanding of how much nitrogen really is necessary.

Often termed as precision agriculture, nutrient management planning is an emerging area in agricultural science. In precision agriculture, farmers test the soil and crop yields of specific plots and utilize this information to plan for and then apply the appropriate amount of fertilizer, water, and/or chemicals that are suited for a particular section of each field (EPA, 2003). Requirements can vary even between one square meter and the next; to implement precision requires extra time and technology to acquire necessary information which does come at a cost. Nutrient management planning has been found to have a 10 percent penalty on farm revenue without any loss of productivity (Bonham, 2006).

Nutrient management planning addresses nutrient export at the point of introduction. This technique can be applied to livestock as well as crops. Dairy precision feeding is an example of a BMP that reduces the amount of nutrients fed to livestock to minimize the amount of nutrients introduced in their excrement. The BMP prescribes a formula of 110 percent of the Nutritional Research Council recommended level of nutrients in feed to ensure milk production is not negatively impacted (CAST, 2011).

For crop-based nutrient management planning, there are a number of technologies that have been developed to facilitate the use of information to precisely treat crops. Some of the advanced technology to administer precision agriculture is variable rate technology (VRT) that uses computerized controllers onboard planting, spraying, or fertilizing equipment to change rates of inputs such as seed, pesticides, and nutrients. An example of this advanced technology is soil probes placed on fertilizer spreaders that continuously monitor electrical conductivity, soil moisture, and other variables to predict soil nutrient concentrations and accordingly adjust fertilizer application in real time (EPA, 2003). Other types of advanced technology include direct sensors that monitor yield, grain quality, salinity meter sleds, weather, and spectroscopy devices (EPA, 2003). These technologies may be cost prohibitive and the range of actual technologies used to collect and monitor data and deploy nutrient management techniques will vary greatly from farm to farm.

Buffer Zones

Planting and maintaining buffer zones close to the edge of streams and rivers prevents erosion and can decrease the concentration of nutrients reaching the water. This is important at all streams and rivers, reducing the access of farm animals to the water as well as providing an uptake (the vegetation) to absorb some of the excess nutrients and prevent erosion. Buffer zones, or riparian buffers as they are alternately known, can be composed of varying species of plants and/or trees and may have different widths from the waterway, but generally the concept is to create a linear area along rivers, stream and shorelines that will help filter nutrients, sediments and other pollutants from runoff as well as remove nutrients from groundwater. Agricultural BMPs call for 100 foot width from the water's edge, with a 35 foot minimum width required (CAST, 2011). Buffers fall into three classes: vegetative (grass), forest, and wetland restoration. Each type provides benefits to a varying degree and specific sites may be best suited for each type.

Riparian buffers not only reduce the export of nutrients from the field to waterways, they have ancillary benefits including streambank stabilization and reduction of erosion, they provide wildlife habitat, improve aesthetics, and provide shade to control water temperature (Bentrup, 2008).

Buffer zones address non-point source pollution of nutrients at the point of export from farms (field edge) into waterways; unlike nutrient management planning which reduces the quantity introduced, buffer zones intend to capture nutrients in runoff and groundwater so that they will be prevented from entering the waterway. The natural state of a riverbank often includes a buffer zone; however this area may be disturbed or threatened from any number of activities. In agriculture, buffer zones may have been destroyed or degraded due to grazing by livestock, replacement of natural vegetation with annual crops or perennial cover, and changes in the hydrologic structure (e.g., slope or embankment material) to expedite drainage from the farm (EPA, 2005).

Physical Exclusions

Physical exclusions can prevent runoff of nutrients, manure, and animals from entering waterways. These would be built structures (like culverts) as opposed to employing vegetative cover to decrease nutrient transport. Types of physical exclusions will vary greatly from farm to farm. Common infrastructure includes: barnyard runoff control, dirt and gravel road erosion and sediment control, irrigation water capture reuse, lagoon covers, off stream watering without fencing, stream access control with fencing, and water control structures. The exclusion of livestock from streams is an important BMP in this category. Livestock exclusion not only reduces nutrient introductions to streams, it also reduces streambank erosion, introduction of biologic organic matter, and can significantly improve local water quality.

If given access, cattle tend to enter streams or other waterbodies to drink and cool off. The stream exclusion BMP requires that livestock have access to an alternative source of drinking water located away from the stream. Shade may also be provided away from the stream to keep cattle out of the water. This BMP may include only the offstream watering infrastructure, or there may also be physical barriers (e.g., fencing) to further reduce water access (CAST, 2011). Limiting or fully excluding livestock from waterways reduces the inflow of manure and reduces erosion which both contribute to nutrient loading.

Cover Crops

The cover crop BMP is a system of year-round cover that reduces soil erosion, slows runoff and takes up excess nitrogen on fields during unproductive seasons (Virginia Department of Conservation and Recreation, 2008). Cover crops may be many different varietals of crop including: legumes, grass, rye, wheat, barley, soy, radish, triticale, winter hardy brassica, or winter hardy oats (CAST, 2011). The choice of crop to plant depends on factors such as cost, availability, and suitability; the type of crop and timing of planting will impact the effectiveness for reducing nutrient export.

Tillage Minimization

Reducing the amount of soil tillage reduces the amount of erosion and is particularly important in areas that are prone to erosion. Maintaining the integrity of the soil is an important approach to reducing nutrient transport and has co-benefits for the new crops as well. Tillage is the traditional practice of turning the soil to control for weeds and pests and to prepare for seeding. Conventional agriculturalists hypothesized that this provided important top soil nutrients to root depths and reduced soil compaction. However, tillage practices have largely been blamed for significant top soil erosion, increased nutrient runoff into waterways, and releasing carbon into the atmosphere. The increased use of plows and tillage in the late 19^{th} century resulted in a trend of declining soil structure and increased susceptibility to crusting, compaction and erosion. The "Dust Bowl", though dependent on an extensive drought, was largely related to tillage practices of the time which made the soil susceptible to intense wind erosion (Lal, 2007).

Tillage minimization can be considered in two categories: conservation tillage where tillage is minimized and continuous no-till where no tillage is practiced in a multi-year, multi-crop rotation. The continuous no-till BMP is a crop planting and management practice in which soil disturbance by plows, disk or other tillage equipment is eliminated; crop residue remains on the field and cover crop planting may be added to maintain moisture in the soil. Conservation tillage specifies a minimum of 30 percent residue coverage at the time of planting along with a non-inversion tillage method (as opposed to no-till).

Land Conversion/Conservation

Planting trees in non-yielding sections of the farm will further reduce erosion, increase nutrient uptake, and act as a carbon sink. Holding sections of the farmland in reserve, conserving wetland, and converting productive farmland to uses that reduce nutrient use and or runoff are all components of this category. These strategies can have multiple benefits and are being encouraged in the public and private sector. Also known as land retirement, the estimated cost for converting land includes the actual activities to convert land from productive farmland and the opportunity cost associated with loss of a productive yield. Land conversion or conservation is a group of BMPs that takes land out of productive agriculture and establishes or protects its use for ecosystem benefits. Examples would be land retirement from intense agriculture to hay, pasture, or forest. Conservation would be committing to set aside an area (i.e., an easement) that could be converted to productive use but will remain in its natural state to preserve environmental benefits. The type of vegetation or use of the converted land will impact the effectiveness of nutrient reduction; however, all conversions have in common that farmers will not introduce nutrients (i.e., fertilize) to those areas thereby reducing nutrient export to some extent.

Manure Management

Managing excess manure is imperative to reducing the amount of organic material that enters streams and rivers upstream of the Bay. One option is to remove manure and transport it to organic farms that utilize it as fertilizer. Other measures can be taken with significant effect including moving manure buildup away from water sources (and keeping animals farther from water sources) and by using rigid containment facilities.

Summary of BMPs

The seven categories of BMPs have specific practices as just described. While the primary purpose of these BMPs is to reduce nutrient runoff, there are also a number of co-benefits that arise from their application. Examples of co-benefits include stream bank stabilization, wildlife habitat, and reduced fuel costs.

Agricultural BMP Effectiveness

The effectiveness of a BMP is the amount of a pollutant that no longer leaves the field when the BMP is applied. For the purpose of the Bay TMDL, effectiveness is measured as a percentage and values for each type of BMP, associated with a specific land use, in a specific hydrogeomorphic location is assessed. The effectiveness values used in the Chesapeake Bay Scenario Tool are the values that would qualify for state WIP compliance and nutrient trading and are therefore of greatest concern for the current research. The following section will describe effectiveness values for the BMPs as found in the literature including those values used in the Scenario Tool.

Nutrient Management

The effectiveness of nutrient management planning depends on the technologies used as well as the pre-planning level of nutrient use and the individual farm characteristics. Agricultural research has found that farmers typically apply 35 percent more nutrients than is required by crops under optimal growing conditions; goals of nutrient management planning are to reduce this by 15 percent (CAST, 2011). With the many types of available technologies and associated costs, the effectiveness of nutrient management planning can vary greatly from farm to farm. One study considered nutrient management plans for a sample of farms in Pennsylvania; the study found that farms nitrogen application could be reduced from 107 kilograms per hectare (44%) on one farm, 164 kilograms per hectare (62%) on another farm, and on a third farm the plan required an increase of 4 kilograms of nitrogen per hectare (5%) (Hamlett, 1994).

There may be a difference between the expected (or potential) effectiveness of nutrient management plans and the actual nutrient decreases realized. Factors such as the experience of the farmer with nutrient management planning can impact the actual quantity of nutrients reduced. It has been suggested that an *imperfect* though practical plan will have superior results to a *perfect*, yet impractical plan to implement (Beegle, 2000). The Pennsylvania (Hamlett, 1994) study utilized models to determine the nutrient management plan and provides insight into the potential reductions; however, actual reductions based on various factors and the amount of nitrogen reduced at the field edge (the amount being transported from the farm to the waterway) are not observed and may not yield the same results.

Buffer Zones

Similar to nutrient management planning, the effectiveness of buffer zones varies greatly. The EPA (2003) identified the following factors that influence the effectiveness of buffer zones in reducing the transport of nutrients from farms: the contaminant (e.g. sediment, phosphorus) to be controlled, the nature of the soil particles, types of practices or controls, site-specific conditions (e.g. crop rotation, topography, tillage, harvesting method), and operation and maintenance of the buffer zone. The effectiveness of forested buffer zones in the Chesapeake Bay watershed has been estimated to reduce nitrogen and phosphorus by an average of 40 percent. For grass buffers the effectiveness has been estimated at 28 percent for nitrogen and 39 percent for phosphorus (average derived from all types/geologies of buffers from the CAST, 2011).

There have been a number of studies which directly measure the effectiveness of buffer zones, albeit on small, experimental plots. A study in the North Carolina coastal plain sampled groundwater wells located below seven agricultural fields. Researchers found that in the three fields with densely vegetated riparian buffers, there was virtually no subsurface nitrogen entering the waterway (Norris, 1993). A meta-analysis of 88 studies of buffer effectiveness indicated a strong correlation in the width of the buffer zone and its effectiveness at reducing nitrogen; those buffers that were less than 25 meters had a mean effectiveness of 58 percent while buffers sized 26 to 50 meters were 71 percent effective and buffers larger than 50 meters were 85 percent effective at removing nitrogen (Mayer, 2007). The meta-analysis also indicated that buffer width alone did not explain the variation in effectiveness of the buffers in the study, but that other factors including type and density of vegetation influence nitrogen removal rates.

Physical Exclusions

Unlike many of the other BMPs, stream exclusion has been found to be much more effective at reducing phosphorus and sediment than at reducing nitrogen. A before and after study was conducted on a small stream in North Carolina and included both fencing, offsite watering, and planting in the buffer zone in an area with intensive cattle pasture. The study found that loading rates decreased by 78.5 percent for potassium, 75.6 percent for phosphorus, and 82.3percent for suspended solids where exclusion fencing was installed (statistically significant) while less reliably (not statistically significant), nitrogen was reduced by 32.6 percent (Line, 2000). The Chesapeake Bay Model assumes an effectiveness of only five percent reduction in nitrogen for offstream watering without a fence and eight percent reduction in phosphorus (CAST, 2011).

Cover Crops

A study by Staver (1998) of the effectiveness of cereal grain winter cover crops was conducted in Queen Anne's County, Maryland; the long term study was a before and after experiment of the implementation of cover crops holding nutrient inputs constant. Staver found that nitrate leaching from the soil were reduced by eighty percent in plots with cover crops as opposed to those that were barren for the winter and spring (pre-cash crop planting); the reduction in nitrogen exported to the waterway was somewhat less with indications that 60 percent reductions could be achieved although this would lag behind soil reductions of nitrate. In comparison to this study, an experiment conducted in the Midwest on a corn-soybean crop showed a reduction in subsurface nitrogen loss of only 13 percent averaged over a three-year period, with considerable annual variability (Strock, 2004). Depending on the practice specifications, the Chesapeake Bay Model assumes anywhere from a two percent reduction in nitrogen for a legume cover crop up to a 30 percent reduction for early planted ryegrass; notably this BMP does not reduce phosphorous export (CAST, 2011).

Tillage Minimization

Effectiveness estimates for no-till range from 10 to 15 percent reduction in nitrogen and 20 to 40 percent reduction in phosphorous runoff. Conservation tillage yields lower results – seven percent reductions of nitrogen and 18 percent reductions of phosphorus runoff (CAST, 2011).

Land Conversion/Conservation

There are many programs to preserve and retire land. The Conservation Reserve Program (CRP) is a federal program which incentivizes farmers to preserve and retire land that is highly erodible; the contracts take land out of production for 10 to 20 years. In 2011, the CRP estimates that its efforts in land conservation led to a decrease in nitrogen of 623 million pounds, 124 million pounds of phosphorus, and 226 million tons of sediment that entered waterways; this represents effectiveness levels of 95 percent for nitrogen and 86 percent for phosphorus (USDA, 2011a). While clearly very effective at reducing nutrient export, land conversion or conservation fully takes an area out of production with high costs of foregone crop yields. On a unit basis, this BMP may be one of the most effective; however, the feasibility of widespread application is limited by productivity requirements.

Manure Management

An experimental BMP to reduce the risks associated with manure application, subsurface application of liquid manure from cattle and swine has been reported to reduce surface runoff of nutrients by 25 percent total nitrogen with no reduction in phosphorus (CAST, 2011). Overall, subsurface manure application has been found to reduce ammonia losses by up to 67 percent as compared to surface application (Leytem et al., 2009) and by 100 percent from poultry litter (Pote et al., 2011). Research by Rotz et al. (2011) indicated that this translates to a 50 percent reduction in nutrient runoff from the field. The installation of physical structures and stabilization of walking paths on barnyards and loafing lots have been shown to be effective at 20 percent in nitrogen and phosphorus reductions (CAST, 2011).

Summary of BMP Effectiveness

The uncertainty associated with effectiveness values between and within practices is a research topic in and of itself. Similar to the research question being posed in the current dissertation, heterogeneity in effectiveness of BMPs at the field-level will affect the actual reduction in nutrient pollution achieved from agriculture. Cost-share payments and credits are based on the practices implemented rather than the outcomes.

There is a growing literature on practice- versus outcome- based environmental measures. Outcome-based programs are gaining traction due to the “potential for more cost-effective, transparent, and effective delivery of environmental benefits, while still harnessing market mechanisms to achieve the greatest efficiency” (Burton and Schwarz, 2013). A recent study surveyed outcome-based programs around the world and recommended an approach to implement outcome-based measures in USDA Farm Bill programs (Culliney, 2014).

In the Chesapeake Bay watershed, effectiveness from the literature is examined and values that ‘count’ are determined by the Chesapeake Bay Program (hereafter the “Program”). The Program is a partnership of federal, state, and local agencies engaged in improving the Chesapeake Bay. It is the preeminent source of data and analysis on the sources and transport of Chesapeake Bay nutrient loads. Table Two provides a summary of the effectiveness level ranges for each BMP within the scope of the current research.

Table 2. Summary of BMP Effectiveness Values in the Literature

Category	BMP	Effectiveness (Percent Reduced)
Nutrient Management	Nutrient Management	N: 15 - 44 P: 0
Buffer Zones	Grass	N: 28 P: 39
	Forest	N: 40 P: 40
	Wetland	-
Exclusions	Offstream Watering (w/o fencing)	N: 5 P: 8
	With Fencing	N: 33 P: 76
Cover Crops	Cover Crops	N: 2 – 60 P: 0
Tillage Management	Conservation Tillage	N: 7 P: 18
	No-Till	N: 10 – 15 P: 20 – 40
Land Conversion/ Conservation	Land Conversion/ Conservation	N: 95 P: 86
Manure Management	Phytase	-
	Subsurface Injection	N: 25 P: 0

The Program utilizes a suite of models that simulate the watershed, the airshed, the estuary, and land use change; these computer models simulate the complex Bay ecosystem and the inputs of pollutants to provide information on the efficacy of current and potential management actions. The watershed model is the most relevant to the current line of research.

The Chesapeake Bay Community Phase 5.3 Watershed Model (watershed model) was developed to simulate the Chesapeake watershed, the river flows, and associated transport and fate of nutrients and sediment (EPA, 2010).The watershed model has gone through several iterations and improvements since it was first developed in 1983. The current version incorporates the entire geographic extent of the watershed (see Figure Three) and simulates the period from 1985 to 2005 (see EPA 2010 for more on the history of the watershed model development).

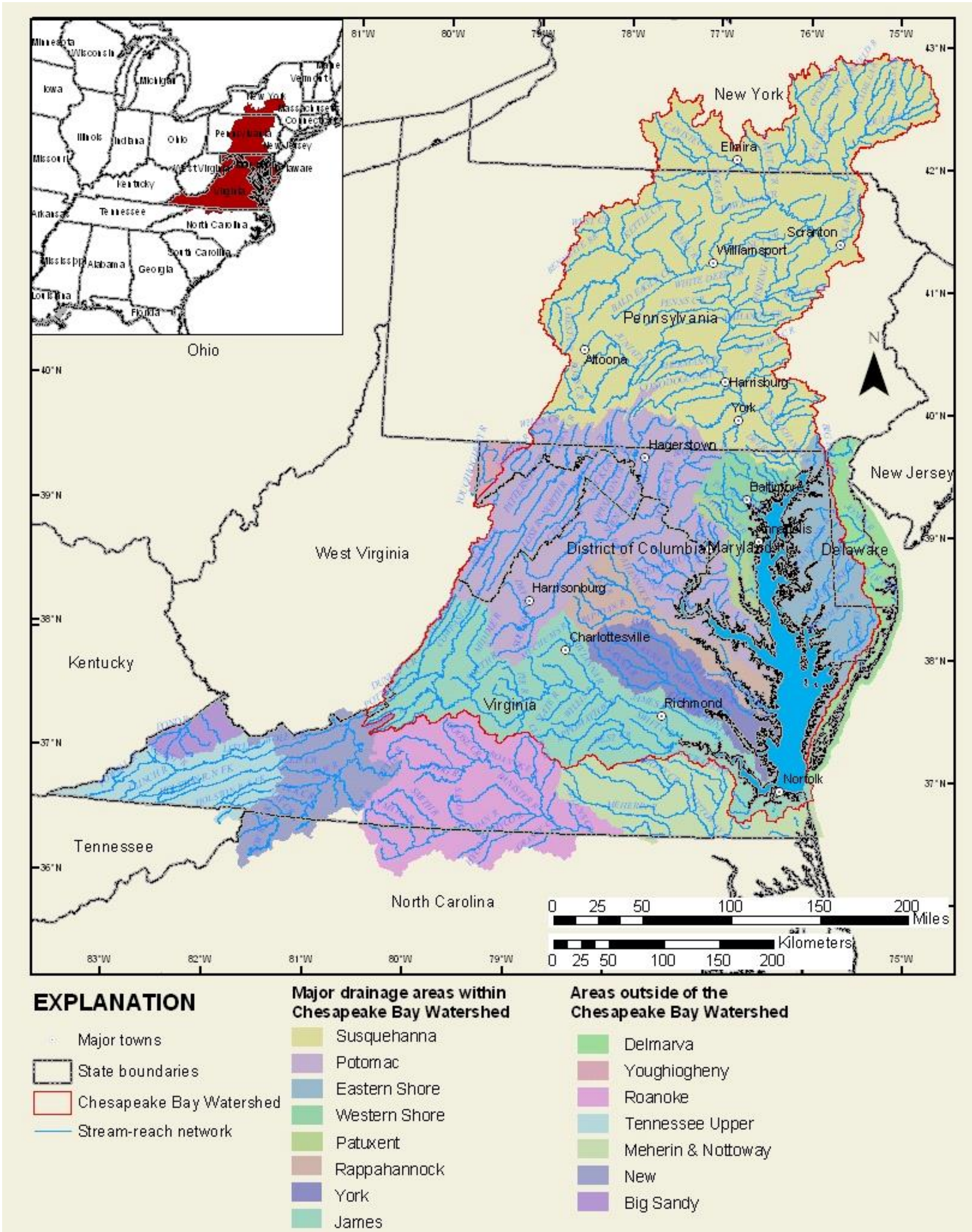


Figure 3.Watershed Model Geographic Extent (EPA, 2010)

The watershed model contains 11 types of cropland and three types of pastureland which have correlated fertilizer and manure inputs for each of the land use categories. The model estimates the annual input (gross) and load (net of attenuation) of nutrients from the land use types based on the amount of fertilizer or manure expected. There is a separate tool called the Scenario Builder which allows the user to change the BMPs and other parameters to see the effect on the actual load.

The Scenario Builder's baseline scenario (relying mainly on data from the Census of Agriculture) estimates the average annual input of nitrogen from agriculture is 1,064,700,000 pounds and 178,400,000 pounds of phosphorous. The module that simulates the fate and transport of nutrient inputs and estimates the load that makes it to the Bay fully simulates forest and crop nutrient cycling, including uptake by plants; the load of nitrogen and phosphorous that actually make it to the Bay in the baseline scenario is estimated at 128,800,000 pounds of nitrogen and 8,300,000 pounds of phosphorus per year (EPA, 2010).

The watershed model contains over twenty types of agricultural BMPs. One of the important revisions in the current version was to try to improve the estimates of BMP effectiveness. The goal is to use science based data and apply factors to attempt to estimate realistic, operationalized BMP effectiveness. This takes into account real world conditions such as variability in climate and practitioner experience (EPA, 2010). The effectiveness rate of any BMP is a function of land use, BMP type, and hydrogeomorphic region; the watershed model BMP effectiveness rates comprise a database of more than 7,000 rows. For example, the effectiveness rate of forest buffer on alfalfa farm land in the

Appalachian Plateau Siliciclastic Non Tidal region achieves a 54 percent nitrogen effectiveness and 42 percent phosphorus effectiveness rate (CAST, 2011). The complete dataset is available at http://casttool.org/Documentation.aspx, Appendix Six. The watershed model applies effectiveness rates to acres of land implementing the BMP and derives the reduction of nutrient removed from the baseline (the initial estimate of nutrient load from the particular land use within the river segment). The watershed model will be used as the basis for effectiveness assumptions.

Agricultural BMP Implementation Costs

The primary line of research for this dissertation is the heterogeneity in costs of implementing BMPs at the field-level. A survey of the literature and expert elicitation was conducted to provide a background on the costs of BMPs. This section provides a brief primer on the types of costs and then details the costs for each BMP category as found in the literature. Costs in this section are in 2014 U.S. Dollars (USD); costs not originally in 2014 USD have been escalated using USDA ERS Agricultural Services, Index for Prices Paid (USDA, 2011b).

Cost Categories

There are a number of cost categories to consider in the estimation of BMP costs including capital costs, operating costs, opportunity costs, total costs, and equivalent annual costs. The ***capital costs*** are those upfront costs required to install or initiate a BMP. Capital costs often include materials, labor for installation, and planning. Once installation or implementation of a BMP is complete there are ongoing or ***operating costs***. Operating costs include materials and labor required for operating and maintenance of the BMP. Another type of ongoing cost is the ***opportunity cost.*** Opportunity cost is the loss of revenue due to activities foregone; for agriculture this is often the reduction or loss of productive farmland to install or implement a BMP or can be a lower yield on the same field as a result of implementation of a practice.

The ***total cost*** can be estimated from the sum of the capital, operating, and opportunity costs over the life of the BMP project design. This provides the total investment required for the BMP. Another useful cost category is the ***equivalent annual cost (EAC)***; this is total cost distributed over the life of the project taking into account the discounted value of future payments.[4] The EAC provides a good measure by which to compare the BMPs; however, it should be noted that a farmer will likely make decisions on multiple factors including the capital costs required, potential financing or funding for upfront costs, and the ongoing operating and opportunity costs that they can reasonably expect to incur.

To integrate the economic costs and physical effectiveness of each of the BMPs, the ***cost efficiency*** is an important measure. For this application, cost efficiency is defined as the cost ($) per percent of nitrogen or phosphorus reduced. The cost efficiency has two implications; for the farmer, the most efficient (lowest cost per percent of nitrogen or phosphorous reduced) BMP will provide the best return on investment if they are considering the sale of a credit. And for policymakers and others interested in reducing the watershed load of nitrogen and phosphorous to the Bay, cost efficiency provides a

4. Future payments are discounted due to factors such as inflation which reduces the purchasing power of a dollar with time. The discount rate incorporated into EACs presented in this paper is 5.0 percent based on the USDA ERS Agricultural Services, Index for Prices Paid (USDA, 2011b) and consistent with the assumptions utilized by EPA in their cost estimations (CBPO, 2013a).

parameter to target practices that achieve the highest benefit for the least cost, the most economically efficient approach which provides the socially optimal solution. Practically, with limited budgets, achieving the most cost efficient reduction in nutrients allows for the greatest quantity of reduction and most environmental quality benefits.

Nutrient Management

The collection of additional information - and equipment that aides in its collection - are the types of costs associated with nutrient management planning. There are upfront, or capital costs, associated with the initial information, analysis, and planning; and ongoing, or operating costs to ensure the proper execution of nutrient management planning. Cost savings can also be realized in terms of lower costs of fertilizer. The estimated average annual cost is the net cost for nutrient management planning after taking into account the capital, operating, and cost savings for nutrient management planning.

The Virginia NRCS (2011) estimated that the cost of plan development is typically $5 per acre. There may also be capital outlays for equipment and the details of the plan itself may vary greatly from farm to farm and depend on the availability of analysis already conducted on farms with similar characteristics. In Virginia, the state cost-share program has a flat rate of $2 per acre in financial assistance for writing the initial management plan; the cost-share rate is estimated to be 75 percent of the cost actually incurred (DCR, 2014a).

The annual expenditures to implement nutrient management planning have been estimated at $70 per acre (NRCS, 2011). While the plan itself may have a cost to implement, nutrient management planning can result in operational savings in the form of less fertilizer. This value has been estimated by the Virginia Soil and Water Conservation Districts (2008) as an average of $15.50 per year on a three-year project basis. The VA cost share program sets a flat rate of $4 per acre annually for nutrient management plan writing and revisions (DCR, 2014a). The cost-share does not incorporate physical implementation such as additional technology for data collection, but is only meant to fund the planning component.

The equivalent annual cost (EAC) is based on a three-year project design life; the EAC for nutrient management planning in Virginia is estimated at $12.04 per acre (NRCS, 2011). Based on a potential cost-share rate of $4 per acre per year, the costs of nutrient management planning do appear cost prohibitive.

With an effectiveness estimate of 15 percent and an EAC of $12.04, the cost efficiency of nutrient management planning is 0.8 or $0.80 per one percent reduction of nitrogen. The Chesapeake Bay Commission estimated that it would cost approximately $90 to reduce a pound of nitrogen using nutrient management. The actual costs of planning and executing nutrient management planning and cost savings achieved by using less fertilizer may vary greatly depending on factors such as farm size, availability of information, and specific technologies utilized.

Buffer Zones

The costs associated with buffer zones can be considered as the upfront costs of installation, ongoing maintenance of the vegetation, and any opportunity costs associated with the installation or preservation of a buffer zone, or the activity foregone (such as

productive cropland) in the buffer zone area. One of the most significant influences in the cost is the opportunity of using the land for its productive capacity. The embankment and buffer area can vary widely in terms of potential for productive capacity and will influence the actual field cost of installing or preserving a buffer zone.
Additionally, it has been indicated that buffer zones can reduce the yield on adjacent fields due to shading, loss of nutrients and moisture to competing trees, increased difficulty in cultivating fields, and increased wildlife damage (Klapproth, 2009).

The upfront costs for grass buffer zones include the costs of planting and establishing the buffer including the seed costs, fertilizer and lime, and labor and equipment (CBPO, 2013a). Assuming the area is seeded with switchgrass, big bluestem, and indiangrass, or similarly priced seeds it is estimated that the cost is $260 per acre (NRCS, 2011). The VA Department of Conservation and Recreation (2011) has a database of the estimated costs associated with installation of forest buffers; the average installation cost per acre is $838. The capital cost of installation for forest buffers includes several factors such as: site preparation, planting and replacement planting, tree shelters, initial grass buffer for immediate soil protection, mowing, and herbicide (CBPO, 2013a) leading to the higher initial costs compared to a grass buffer. The VA cost-share program has a set rate of $50 per acre for herbaceous buffers and $100 per acre for forested buffers annually for up to five years (DCR, 2014a).

The cost estimate for grass buffer zones does not have an annual operating cost for management, but rather assumes that after initial seeding and establishment there is no additional input to maintain the buffer zone for a project design life of 10 years (MD

DNR, 1996). There are, however, opportunity costs that can be considered as an annual cost via the loss of revenue. For both grass and tree buffer zones, the productive capacity of the area where the buffer is installed determines the revenue foregone in terms of lost crop yield. The opportunity cost has been estimated as the average annual rental rate for riparian buffers; this value is estimated at $59.03 per acre per year in Virginia (CBPO, 2013a based on Farm Service Agency data). The rental rate for property in Virginia varies widely –from $18 to $83 per acre (CBPO, 2013a) – and therefore the actual opportunity cost to any farm or field for installing a buffer will differ from the average value. Forest buffers also do not have annual maintenance costs and have a larger design life compared to grass buffers at 15 years (CBPO, 2013a).

The EAC for a grass buffer includes the upfront investment and the annual opportunity cost of the land for the life of the design (10 years) and is estimated at $92.71 per acre; forest buffers with a design life of 15 years have an estimated EAC of $139.79 (CBPO, 2013a). Based on the state cost-share rates of $50 and $100 per acre, and the potential to combine these funds with federal NRCS funds, there may be enough incentive to motivate farmers to implement buffers depending on specific farm factors.

Grass buffers have an effectiveness estimate of 28 percent and an EAC of $97, yielding a cost efficiency of 3.5 or $3.50 per one percent reduction of nitrogen. The Chesapeake Bay Commission (2012) estimated the efficiency for grass buffers is $40 per pound of nitrogen. For forest buffers, the effectiveness is estimated at 40 percent and the EAC is estimated at $151, leading to a cost efficiency of 3.8 or $3.80 per one percent reduction of nitrogen. The Chesapeake Bay Commission (2012) estimate is $90 per pound of nitrogen removed.

Physical Exclusions

Livestock exclusion, similar to buffer zones, comes at a cost to farmers without many direct benefits. Rather than having access to free fresh water in streams and literally sending the externalities downstream, exclusion requires investments in facilities such as permanent or portable water troughs, pipelines, development of onsite springs or water wells, and fencing or other barriers to stream access (CAST, 2011). In addition to the installation and maintenance costs, exclusion fencing takes pasture acreage out of production (or availability) to livestock and may reduce the productivity or require supplemental feeding of animals (Agouridis, 2005). The costs associated with livestock exclusion create a barrier to the implementation of this BMP, in particular with high up-front costs associated with the physical infrastructure. Virginia's watershed implementation plan recognizes the significance of livestock exclusion and considers it a priority BMP (along with 35-foot buffer zones, conservation tillage, and cover crops) and is implementing cost-share, tax deduction, and education programs to encourage full adoption of this BMP (Commonwealth of Virginia, 2010). The cost analysis is focused on alternative watering with and without fencing.

The capital costs for installing alternative watering without fencing are highly dependent on the farm size, the amount of livestock, and how much water is required for their consumption. It is expected that economies of scale will be achieved as the farm size increases. Wieland (2009) estimated the costs of alternative watering facilities based on information on practices in Maryland; capital costs include either a well with a pressure fed trough and the associated costs of materials and installation or pipeline and a concrete trough depending on the size of the farm and number of animals for which practice is the least cost. For a farm with only one acre, the estimate for the cost is $3,084 per acre; for 50 acres, the capital expenditure is $228 per acre; and for 100 acres the estimate is $158 per acre (Wieland, 2009).

For alternative watering with fencing, also known as stream access control, all of the costs for the alternative watering source are still incurred. In addition, the cost of materials and installation of a fence increases the upfront cost. The capital expenditure for a one acre farm for alternative watering with fencing is estimated at $3,532; for a 50-acre farm the capital costs are $291 per acre; and for a 100-acre farm, the costs decrease to $203 per acre (Wieland, 2009).

These values are all based on average distances required to bring the water to a watering trough and are likely to vary substantially from farm to farm. A consideration that Wieland did not take into account is the competing uses, or opportunity cost, of using groundwater for livestock consumption. Stream exclusion is a priority BMP and provides not only important nutrient reductions, but has a high impact on local water quality issues therefore the VA state cost-share has a 100 percent rate for stream exclusion projects (not including offsite watering costs) (DCR, 2014a). In 2013, the VA cost-share program paid between $551 and up to $89,000 for stream exclusion projects; the per acre cost varied from $25 to $15,000 signifying the heterogeneity in costs incurred for stream exclusion (DCR, 2014b).

Wieland did not estimate any ongoing costs for alternative watering with or without fencing; it is assumed that the landowner has rights to the water that is being consumed and that there are not ongoing maintenance costs associated with the infrastructure. The estimated design life is ten years for this BMP based on these assumptions (CBPO, 2013a).

The EAC was estimated by the Chesapeake Bay Program Office (2012) based on a discount rate of five percent over the expected ten year life of the project. For alternative watering without fencing the EAC is $399.43 per acre for a one-acre farm; for a 50-acre farm the EAC is $29.51 per acre; and for a 100-acre farm the EAC is $20.52 per acre (CBPO, 2013a). For alternative watering with a fence the one-acre farm EAC is $457.36 per acre; the 50-acre farm is $37.70 per acre; and the 100-acre farm is $26.31 per acre (CBPO, 2013a).

Assuming the 50-acre farm EAC of $29.51 and an effectiveness of 5 percent, the alternative watering without fencing BMP has a cost efficiency of 5.9 or $5.90 per one percent reduction of nitrogen. For the alternative watering with fencing BMP and a farm size of 50 acres, the EAC is $37.70 and the effectiveness is estimated at 8 percent yielding a cost efficiency of 4.7 or $4.71 per one percent reduction of nitrogen. The Chesapeake Bay Commission (2012) estimated that offstream watering would cost nearly $600 per pound of nitrogen removed. It is important to note that both of these BMPs are found to have high phosphorus effectiveness and also reduce other pollutants with a large impact on local water quality in addition to the reduction of nutrients that reach the Bay.

The Chesapeake Bay Commission (2012) estimated that to reduce a pound of phosphorus using offstream watering, it would cost nearly $1,200.

Cover Crops

Cover crops have material (seed), installation (equipment and labor), and maintenance costs. Except for the capital costs that may be incurred for planting equipment, all of these costs will occur annually as long as the farmer decides to continue the practice. Since cover crops are planted after the harvest, they do not compete with commodity crops therefore don't have an opportunity cost.

The capital and operating costs of cover crops are not disaggregated in the literature. Virginia NRCS (2011) estimates that the annual cost of cover crops per acre per year ranges from $55 to $140 for specialty crops; basic cover crops are approximately $26 per acre per year. The average rate used by the Chesapeake Bay Model is $109.38 (EPA, 2013draft). The Agricultural Research Service (USDA ARS, 2013) developed a cost estimate for establishing and terminating a rye cover crop in the southeastern United States. For establishment, the cost of cereal rye seed is $52.20 per acre and no-till drilling is $9.80 per acre. Fertilizer costs $19.86 per acre and it application adds $6.29 per acre. Before the next season, termination of the cover crop can be either chemical or mechanical and the ARS found that chemical termination costs are $3.42 per acre and mechanical is $4.00 per acre. The total cost according to this estimate is $95.57; more than half of the cost is due to seed price and will vary with which type of cover crop is planted.

The VA cost-share program provides a set rate of $25 per acre with a $25 per acre bonus for early planting and a $10 per acre bonus for select rye varieties (DCR, 2014b). The cost-share program is designed to encourage the use of crop types and planting timing that provides the greatest nutrient uptake.

Cover crops have an EAC ranging from $35 to $41 per acre and effectiveness varies widely from two to 60 percent reduction in nitrogen. The cost efficiency for cover crops could be as low as 0.6 or $0.60 per one percent reduction of nitrogen to as much as 17.5 or $17.50 per one percent reduction in nitrogen. The Chesapeake Bay Commission (2012) estimated that it would cost $50 per pound of nitrogen removed. The actual cost efficiency for specific types of cover crops can be estimated with detailed analysis of the seed price and effectiveness of the cover crop in nitrogen uptake.

Tillage Minimization

There is contradicting information on the costs of both tillage minimization and continuous no-till in the literature. Theoretically, both capital expenditures (or gains) in the form of equipment, operating expenses such as labor and fuel, and impacts on yield will all be costs (or benefits) from conservation and no-till agriculture.

The average annual cost for conservation tillage is estimated by the Delaware Chesapeake Interagency Working Group (2010) as $13 per acre. For continuous no-till, the VA DCR (2014a) estimated that the annual cost per acre at $25. Boyle (2006) assessed the cost of both tillage minimization and continuous no-till and determined that the “adoption of soil-conserving practices doesn’t have a significant impact on profit returns, indicating that these practices are profit neutral.”

What is consistent in the literature is that there is different equipment required for planting under a no- or low- till regime than traditional practices with associated costs. On the positive side of the accounting, no- or low- till reduces the effort of farmers on the land and associated labor and fuel costs are reduced. The planter costs for no-till and conventional methods have been estimated with no-till planters coming in at approximately $40,000 and conventional planters at $14,000 signifying a large difference in potential capital expenditure (Weiland, 2009). No-till may also increase the use and cost of herbicides. Weiland (2009) concludes that based on the literature there is a net-positive effect with the implementation of no-till over time.

The VA cost-share program has a set rate of $100 per acre for the five year lifespan (DCR, 2014b). When considering the cost of a planter at $40,000, a farm size of at least 80 acres would be able to pay off the equipment in full with a cost-share for five years. If it was already time for the farmer to replace their conventional planter, and only the marginal cost of a no-till planter is considered (~$26,000) then a farm with a minimum size of 52 acres would be able to fully pay off the incremental cost of the equipment with the cost share. This simple analysis does not even incorporate the potential benefits of less fuel and labor; estimated by Bradley (1991) as close to half for no-till practices in comparison to conventional tillage. No-till has also been recorded to increase productivity; Lee (2007) estimated that no-till farms yield an average of 8 more bushels of corn per acre per year. At today's corn prices (Schober, 2014) this is equivalent to more than $40 per acre. The value proposition of tillage minimization and continuous no-till seems clear for farmers; however, the high up-front cost of equipment and willingness to change traditional methods remain barriers to higher adoption rates of these BMPs.

For conservation tillage, the EAC is estimated at $13 and with an effectiveness of seven percent; the cost efficiency can be estimated as 1.9 or $1.90 per one percent reduction of nitrogen. The no-till BMP has an EAC of $25 and an effectiveness of 10 to 15 percent yielding a cost efficiency of 1.7 to 2.5 or $1.70 to $2.50 per one percent reduction of nitrogen. The Chesapeake Bay Commission (2012) estimated that continuous no-till would cost $50 per pound of reduced nitrogen. A caveat to these cost efficiency estimates is the indication in the literature that tillage practices may actually be profit neutral which would lead to a 0 or even negative (profitable) cost efficiency for reduction of nitrogen.

Land Conversion/Conservation

The major cost associated with conversion of marginal or highly erodible cropland is the loss of productive farmland or the opportunity cost of initiating the practice. Additionally, there are factors associated with planting vegetative cover or forest on the land.

The Maryland Department of the Environment (2010) estimated the cost of land conversion of a 2,300 acre area of highly erodible cropland at $3,000,000. The estimate includes both the opportunity cost of the productive land and the costs of conversion. On a per acre basis, this is equivalent to $1,304. The actual cost of implementing land conversion will vary greatly based on the productive capacity of the land, the type of crop that would have been planted, and the crop prices. Another factor that is likely to influence the cost of land conversion is the precise activities required to preserve the land and the associated costs of those activities. Of note, in 2012 the National Agricultural Statistics Service estimated the rental rate of farmland in Maryland is worth $91 per acre while in Virginia the rate is estimated at $52 per acre (NASS, 2014). This indicates that the implementation of land conversion in Virginia will be considerably less than the cost estimate provided by the Maryland Department of the Environment.

The design life of land conversion used for the Maryland estimate is 10 years. On an annualized basis, land conversion is therefore $169 per acre per year. The VA cost-share program provides assistance for implementing 'reforestation of erodible crop and pasture land' at a rate of $25 per acre plus 75 percent cost-share of components for a 10-year contract and $50 per acre for a 15-year contract. There are also opportunities with the federal NRCS to receive additional funding. The value proposition is highly dependent on the productive capacity of the area and the going price of commodity crops.

With an estimated EAC of $169 and an effectiveness of 95 percent, the cost efficiency for the land conversion/conservation BMP is 1.9 or $1.90 per one percent of nitrogen reduced.

Manure Management

The cost to transport a ton of manure on average in the Mid-Atlantic is $27.53 (CBPO, 2013a). There may be other costs such as containment facilities and there may be opportunities to recoup some of the costs if the farmer is able to sell the manure as fertilizer. Manure management has two different meanings – the control of animal manure from livestock living on the farm and the management of manure applied to cropland for the purpose of fertilization. The scope of the current paper is limited to non-point source pollution and large livestock operations – i.e., confined animal feeding lots (CAFO) – are considered point sources by the EPA therefore the BMPs that might apply to CAFOs will not be described. For the farms that maintain small numbers of livestock, there are manure management BMPs to consider. For poultry and swine, there is an additive known as phytase that can be added to feed to reduce the levels of phosphorus in the excrement, thereby reducing the amount that may runoff the farm.

Many farms use manure as a fertilizer or in combination with chemical fertilizers to provide the necessary nutrients to crops. However, as described in the nutrient management planning BMP, often too much is used and nutrients are exported from the farm via surface runoff or throughflow. An experimental BMP to reduce the risks associated with manure application is the subsurface application of liquid manure from cattle and swine. Research studies have shown that this can significantly reduce the surface runoff of nutrients; current estimates for effectiveness are 25 percent total nitrogen and no reduction in phosphorus (CAST, 2011). It is important to note that this BMP is still largely experimental and not currently being widely deployed.

Manure management costs depend on the potential demand for manure as fertilizer on other farms. With this scenario the costs of collecting and transporting manure are offset to a degree by the revenue generated from selling the manure. In other scenarios, approaches such as liquid manure injection accrue costs without the possibility of revenue.

The USDA (2003) estimated the costs associated with managing manure for water quality and the numbers have been escalated to 2011 dollars by EPA (CBPO, 2013a). The estimate includes a base charge of mixing, loading, and spreading manure which ranges depending on whether the manure is held in a lagoon, as slurry, or dry with costs ranging from $5.48 to $27.39 per ton. Common distances for transport are 5.5 miles and 40 miles; the USDA averaged the cost of hauling over these two distances and including the base charge the total cost of transport ranges from $24.18 to $34.25 with an average of $27.53. All of these costs are operating, or ongoing costs. There may also be capital costs of infrastructure for holding the manure between transports. The VA cost-share program will support the installation of animal waste control facilities and composting facilities at a rate of 75 percent (DCR, 2014b). This level of support for the infrastructure is likely a good value proposition for a farmer with adequate demand for the manure. With a large share of the capital expenditure cost-shared and the ongoing transport costs more than covered by the revenue generated by the sale of manure as fertilizer, it is likely that the farmer could recoup all of their expenditures and provide the environmental benefit as a bonus.

Liquid manure injection costs were estimated by the Maryland NRCS (2011) at a rate of $60 per acre per year. Liquid injection reduces runoff of nutrients even further and may be done by farmers on crops using their farm's manure or purchased from another location. There are no cost supports for this activity and the information on adoption and effectiveness are less well documented than surface application.

With an EAC transport cost of $28 per ton and an effectiveness of 25 percent, the cost efficiency for manure management is 1.1 or $1.10 per one percent reduction of nitrogen. The actual effectiveness for manure management will vary with the type of holding facility on the farm and may contribute nutrient export at the receiving farm if too much is applied or the application is poorly timed.

Summary of BMPs

Overall, the average costs of BMPs on a per acre basis vary widely depending on the practice. Nutrient management is on the low end of costs at an average rate of $12 per acre (NRCS, 2011). The highest costs are buffer zones and land conversion, largely due to the opportunity cost associated with those practices. Table Three provides a summary of the costs of the BMPs from the literature.

Table 3. Summary of BMP Average Annual Costs from the Literature

	Nutrient Manage-ment	Buffer Zones		Physical Exclusions		Cover Crops	Tillage Minimization		Land Conversion/ Conservation	Manure Manage-ment
		Grass	Forest	W/O Fence	W/Fence		Conservation Tillage	Continuous No-Till		
Annual Cost ($/acre)	$12	$93	$140	$30	$38	$35-$41	$13	$25	$169	$28

Source: Costs as cited in previous section.
Physical exclusions assumes 50-acre farm size estimate

Additional Factors Influencing Farmers' Willingness to Participate

Farmers' willingness to participate in the trading market by implementing BMPs on their fields may have explanatory variables beyond the expected cost and benefit considerations. Research has shown that farmers typically take into account the payment level, farm specific factors, farmer factors, community factors, the practices themselves, and geophysical and social contextual factors when determining whether or not to join a program that encourages conservation or other environmental protection (Prokopy et al, 2008). Research also indicates that farmers consider the inherent risks associated with changing production practices and account for those in financial decisions (Kurkalova et al., 2006).

Cultural aspects of farmers are among the most important in convincing farmers to participate. Farmer knowledge as a function of age and education level, beliefs, and attitudes all influence the decision of whether or not to participate in voluntary programs (Reimer, 2012). A choice experiment found that one additional year of education increased the probability of participation in a payment for environmental service by three percent (Shan Ma et al., 2012); interestingly, the same study found that while willingness to participate is subject to many cultural factors, once this hurdle has been overcome, the field-level decision is based strictly on benefit-cost ratios.

There is some evidence that there is a wariness to get involved with a government managed program. Farmers may get disutility from the managerial effort required to maintain BMPs and/or dislike the procedures associated with environmental trading regimes. In particular, farmers may find the intrusiveness associated with being inspected or monitored to ensure BMPs are in place objectionable and refuse to participate on this fact alone (Peterson et al., 2007).

There are a number of barriers to adoption in addition to costs that have been identified for nutrient management. The Department of Agriculture (USDA) identified the following seven types of barriers: producer attitudes, information issues, technology, economic issues, operation and management issues, training issues, farmer/rancher record keeping (Brant, 2003). Producer attitudes are related to the belief in whether or not one needs to implement a nutrient management plan and a general distrust of the government (whom often provide information or encourage practices such as nutrient management planning). Information is the keystone of nutrient management planning and it requires technology, time, and resources to collect; this is a barrier to implement nutrient management planning as well. Other issues that USDA has identified are lack of knowledge or training about this approach and its potential benefits (e.g., cost savings on fertilizer or gasoline).

For cover crops, there are several barriers related to implementation including farmer hesitation due to potential foregone revenue from cash crops, timing issues relative to cash crops, and the costs of planting a cover crop (Virginia Department of Conservation and Recreation, 2008). A survey of vegetable farmers in New York found that 26 percent of farmers did not implement cover crops due to the interference (or perceived interference) of cover crops with spring planting or fall harvest (Young, 1999). There is not currently national information on the adoption of cover crop practices; however, a number of surveys (mainly in the Midwest) have revealed a range from less than one percent (of acres) to twelve percent (of farmers) implementation of cover crops (National Wildlife Federation, 2012).

Farmers that regularly engage in cover cropping practices have identified the following benefits from the BMP: reduced soil compaction, reduced soil erosion, nitrogen scavenging, weed control, increased yield of future cash crops, decreased future production costs, winter hardiness, disease reduction, and insect control (Werblow, 2013). Those same farmers also reported an average of 9.6 percent greater corn yields after cover crops and an 11.6 percent increase in soybeans during the 2013 growing season when drought negatively impacted national crop yields.

Unlike many of the other BMPs, tillage minimization practices have been widely adopted. According to the USDA (2013), 35 percent of cropland in the United States had no-till operations in 2009. Farmers can realize direct benefits from no-till practices including reduced cost of equipment and lower maintenance and fueling requirements of equipment; however, no-till practices typically require the use of herbicides to control for weeds and this has both cost and environmental implications. Increases in no-till practices in the U.S. are not continuing to rise at the same pace as previously and this may be due to barriers including subsidies that discourage farmers from diversified crop rotations and interest groups lobbying against the adoption for commercial reasons. Additional barriers identified worldwide are: mindset (tradition, prejudice), knowledge on how to do it, availability of adequate machines, availability of adequate herbicides, and adequate policies to promote adoption (Derpsch, 2010). Another issue related to herbicide use is the emergence of herbicide-resistant weeds (Christ, 2013). Considerable research to reduce the need for herbicides and prevent the occurrence of more herbicide-resistant weeds related to no-till is ongoing.

Farmer behavior and decision-making will ultimately affect the number of nutrient credits provided and the total cost of implementing the TMDL. Previous studies have considered the costs and transaction fees and even risk aversion behavior; however, to accurately estimate the number of credits and magnitude of pollution reduced from agricultural BMPs via credits, it is necessary to understand the nonmonetary factors that influence farmers' willingness to participate. Table Four summarizes the BMP specific factors that influence farmers' participation in markets.

Table 4. Summary of Barriers to BMP Adoption

Category	BMP	Barriers
Nutrient Management	Nutrient Management	Producer attitudes, information, technology, cost of implementation, operation and management issues, risk of reduced yield due to nutrient reduction
Buffer Zones	Grass	Cost of planting, maintenance, foregone productive acreage (revenue); May reduce yield on adjacent fields
	Forest	
	Wetland	
Exclusions	Offstream Watering (w/o fencing)	Cost of installing offsite water, fencing, maintenance, reduced access to waterway
	With Fencing	
Cover Crops	Cover Crops	Reduced yield from cash crops, timing issues with cash crops, cost of planting cover crop
Tillage Management	Conservation Tillage	Use of herbicides and associated costs, producer attitudes, insufficient information and training
	No-Till	
Land Conversion/ Conservation	Land Conversion/ Conservation	Foregone productive acreage (revenue)
Manure Management	Phytase	Experimental, yet to be determined
	Subsurface Injection	Suitability with no-till not yet understood

Economic Basis for Nutrient Trading Markets

One way to reduce nutrient loads is via prescriptive regulation; for example, requiring specific load reductions from wastewater treatment plants. However, economic theory lends itself to develop approaches that can achieve the same benefits with a more efficient and less costly allocation of resources. There are opportunities for cost savings by trading nutrient credits via a market-based approach (Senate Finance Committee, 2011).

Adam Smith first introduced free market theory where "Every individual … intends only his own gain, and he is in this … led by an invisible hand to promote an end which was no part of his intention..." (Adam Smith, 1776). This invisible hand leads the market to provide a sufficient supply of those goods and services that are demanded by individuals. A market failure, however, is a situation in which the amount of a good supplied is unequal to the amount demanded. In the context of nutrient pollution, too much nutrient pollution is being produced. The nutrient pollution causes an externality.

The concept of ***externalities*** is that an activity can result in an impact (negative or positive) that is not internal to the accounting of the activity. In this case, the activity is agriculture. The agricultural producer operates based on the most efficient level of production, where the marginal cost of the last unit of production equals the price that can be earned in the market (based on demand). For example, a farmer will produce an additional ear of corn at the price of $4.50 per bushel until the last bushel's unit cost to produce exceeds $4.50.

The farmer's efficient quantity of supply takes into consideration the costs of production including labor, capital, and materials. However, externalities, in this case eutrophication as a consequence of too much nutrients, are not accounted for by the farmer since he does not bear the cost nor reap the benefit. Instead, the cost of eutrophication is borne by society.

These costs come in the form of lost ecosystem services (i.e., the value that humans derive from the environment) as a result of ecological damage. The economic impacts of impaired water quality are well studied. Lipton and Hicks (1999; 2003) and

Bricker et al. (2006) found that aesthetics (i.e., water clarity) and fishing opportunities and success were reduced as a result of nutrient enrichment. Hoagland et al. (2002) demonstrated that eutrophication reduced tourism and real estate value. Residents, recreationists, and others suffer from eutrophication while the farmer is not directly impacted and not required to compensate those that do suffer for damages.

Pigou first identified the divergence of the producer's interests and society's interests (Pigou, 1920). Pigou recommended that to correct the inherent market failure, the government must intervene with a tax that should approximate the marginal cost of the externality so that the socially optimal equilibrium could be achieved (Pigou, 1920). The taxes, which came to be known as Pigouvian taxes, would increase the producer's marginal costs such that they would shift the production curve. Under these new market conditions, the government would collect revenues and would theoretically compensate those impacted by the externality. This would result in the social optimum where the externality is reduced and those that are still harmed by the remaining externality can be compensated by the tax revenue.

The installation of BMPs would provide a positive externality whereby the provider does not get rewarded or compensated and leads to an undersupply of BMPs. Relying on polluters to 'do the right thing' would ignore the tenants of the market and individuals' motives to satisfy their own needs by contributing to the market. Shortle et al. (2012) and Kling (2011) noted that relying on voluntary implementation of BMPs is inconsistent with the 'polluter pays' principle and implies that property rights to pollute belong to the farmer rather than society.

If society were determining the optimum supply of production, the costs associated with impaired water quality would be included (costs may be to prevent pollution or compensate for damage), increasing the marginal cost associated with each unit of production and reducing the quantity of supply. Figure Four depicts this dichotomy. In the graphic below on the left, the $\text{Supply}_{\text{producer}}$ represents the producer's supply curve and $\text{Supply}_{\text{society}}$ represents society's. $\text{Supply}_{\text{society}}$ accounts for the externality and therefore the cost of each unit of production is higher. Demand is based on consumers' willingness to pay for the product; with quantity demanded decreasing as the price rises. The market equilibrium is the point at which the supply and demand curves intersect. The market equilibrium for society is a lower quantity of products at a higher price with less nutrient pollution. The difference in the supply curves creates dead weight loss which is the amount by which the social cost outweighs the social benefit.

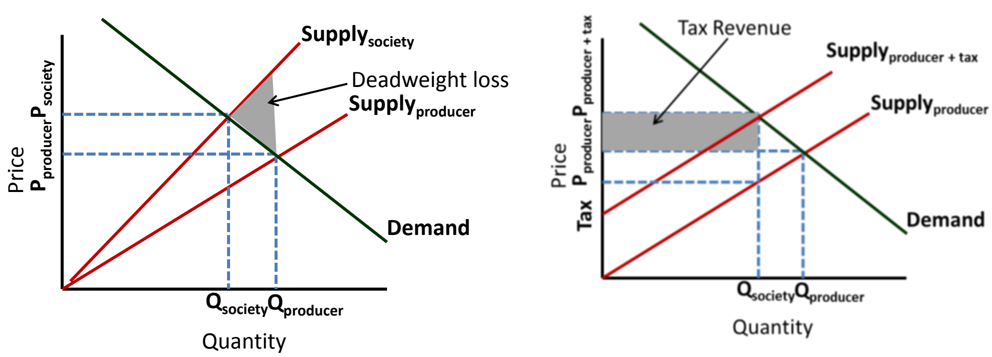


Figure 4. Producer versus Societal Market Equilibrium: Business-as-Usual and with a Pigouvian Tax

The graphic on the right shows how a tax would influence the producer's supply curve. By increasing the unit cost of each bushel of corn for example, the farmer would supply less. The government could collect tax revenue for nutrient pollution and compensate society for impaired water quality.

Pigouvian taxes have been criticized for imperfectly measuring marginal social costs or benefits (Barthold, 1994). Policy-makers have to determine the deadweight loss created from an externality and set the tax rate such that it shifts the supply curve in the right direction and by the right amount. In policy implementation this is a challenge and setting the tax rate to induce a specific reduction in pollution or increase in ecosystem services may never occur perfectly. For many years, Pigou's theorem dominated economic ideology for pollution abatement. However, in 1960, Ronald Coase argued that a Pigouvian tax is not necessary to achieve the social optimum, and in some cases it is detrimental (Coase, 1960).

Coase argued the market could achieve the optimal level of a produced good that results in less external impacts through negotiations of private parties under certain conditions. Coase's work relied on two important assumptions: 1) property rights must be well defined and 2) there are no (or very minimal) transaction costs. If these two assumptions are valid, than the private parties will find the least cost solution to resolve the externality associated with production.

Coase recommended that the government should strengthen property rights (and make them transferable) and provide ways to reduce transaction costs. Coase's work provided the foundation for cap and trade policy instruments. Fundamentally, cap and trade assigns property rights on environmental degradation (or protection) making individuals liable and allowing for trading among regulated parties so that they can achieve a given pollution reduction at the lowest cost.

In policy implementation, the cap and trade mechanism provides an upper biophysical limit on pollution which provides an assurance that environmental goals will be met. The market leverages the ability of some parties to provide environmental goods, services, or amenities at a lower cost than others. The heterogeneity in cost of supply provides an opportunity to increase the economic efficiency of achieving a given environmental objective (Hoag and Hughes-Popp, 1997). For instance, the cost of removing a pound of nitrogen may be $5 for a farmer while it costs a water treatment plant $50 (illustrative). This heterogeneity in cost allows the buyer – the water treatment plant manager – to pay the farmer to achieve the nutrient reduction. This is a win-win-win; whereby pollution is reduced, the farmer is compensated for installing the BMP, and the water treatment plant manager has a lower cost.

Early attempts to wield economic theory to provide environmental benefits occurred in the 1970s. These initial efforts employed Pigouvian tax mechanisms. Largely focused on energy conservation at that time, from 1978 to 1986 Congress established a tax credit for residential energy conservation expenditures trying to encourage the use of more efficient products through a subsidy (Barthold, 1994). In 1978, Congress enacted a gas guzzler tax aimed at encouraging sales of vehicles with higher fuel economy (ibid); similar to the tax credit, this policy was aimed at encouraging consumers to purchase more efficient vehicles by increasing the unit price of less efficient models (via the tax).

In the 1990's there was a shift to the more market-based approach of cap and trade. The sulfur dioxide trading program initiated under the 1990 Clean Air Act Amendments (Public Law Number 101-549, 104 Statute 2399) limited the amount of sulfur dioxide emitted by electricity generating power plants. The program was instituted using a cap-and-trade mechanism which allowed firms to trade sulfur credits as a way to reduce their overall cost of compliance. This approach capped total emissions while allowing firms with heterogeneous costs to produce more or less emissions and trade credits to achieve cost efficiency (USDA, 2011).

The potential benefits of environmental trading markets have been recognized for nearly fifty years (Crocker, 1966 and Dales, 1968). The EPA has been emphasizing the utility of a trading market for water quality as a significant management tool over the past two decades (EPA, 1996, 2003). In 2004, Breetz et al. conducted a comprehensive survey of all of the water quality trading markets in the United States and found that there were 75 markets. Current estimates vary widely from 21 active and pilot programs (Fisher-Vanden and Olmstead, 2013) to 60 programs (Selman et al., 2009). Trading in nutrient markets across the country has been "strikingly" low (Fisher-Vanden and Olmstead, 2013). Nutrient credit markets may be nascent, but there is a long legacy of employing market-based mechanisms to achieve environmental objectives in the United States. The next section will describe the rules in Virginia's nutrient credit trading system followed by a discussion of the efforts to assess the potential economic efficiency that could be achieved by a Chesapeake Bay nutrient trading market.

Virginia Nutrient Market 'Rules'

The 2005 Virginia legislation (Virginia General Assembly, 2005) that establishes the regulatory basis for nutrient market trading also prescribes the 'rules' for trading. According to the Chesapeake Bay Watershed Nutrient Credit Exchange Program rules, point sources can purchase nutrient offsets from non-point sources to meet nutrient discharges in excess of load caps (VDEQ, 2008). According to the Virginia Department of Environmental Quality (2008) there are a number of key criteria that must be met for a trade to comply with Virginia regulations and include:

- Non-point nutrient reductions must be in a ratio of 2:1 to offset point source increases (e.g., for every one additional pound of nitrogen being contributed by a wastewater facility, a two pound nitrogen reduction must be attained by a BMP),
- Offsets must occur in the same calendar year as additions,
- Offsets must occur in the same tributary as additions,
- Nutrient reduction offsets must be above and beyond those required or funded by federal or state law, i.e., nutrient reductions must exceed the *baseline*, and
- Only four BMPs are eligible as offsets.

Setting a trading ratio is to account for the uncertainty in non-point source nutrient reductions compared to the relatively certain point source contributions (VDEQ, 2008). The ratio influences the cost to offset a pound of point source nutrient reduction. In comparison to Virginia's 2:1 ratio, Maryland has established a 10 percent credit retirement stipulation and Pennsylvania has a ratio of 1:1 with a 10 percent reserve account (CBC, 2012).

Similar to setting a trading ratio, the requirement for offsets to occur in the same calendar year and in the same tributary is related to ensuring water quality goals are met. However, these stipulations limit the number of potential trades. Requiring farmers to meet a baseline increases the cost of entry to the nutrient trading market (Ghosh et al., 2011).

BMP Baseline

To be eligible to generate offsets, a tract must have attained all of the BMPs included in the baseline according to the Virginia Nutrient Management Program standards. The baseline includes implementation of the BMPs: soil conservation, nutrient management, cover cropping (cropland only), livestock exclusion (pasture only), and riparian buffer installation. The livestock exclusion practice requires that fencing is installed to restrict livestock from entering all perennial streams, rivers, lakes, ponds or other surface waters. Alternative watering must be provided and a riparian buffer with a minimum width of 35 feet is required. For cropland, a riparian buffer with a minimum width of 35 feet is also required.

According to the guidelines, use of cost-share funds (federal and/or state) for the installation of any of the baseline measures is acceptable. The significance of the baseline requirement is that farmers must implement these BMPs before they are eligible to provide nutrient reductions for credit. This increases the actual costs to establish a BMP for trade to the extent that cost-share funding does not cover costs.

BMPs Eligible for Offset

There are currently a limited number of BMPs that are eligible for credit generation. All of the BMPs allowed in the Nutrient Management Trading Program apply to cropland and not livestock. Early planted cover crops, fifteen percent nitrogen reduction on corn, continuous no-till, and land conversion are the only BMPs eligible as an offset. It is notable that in previous legislatures (2012) additional practices were recommended and are still being considered for credit in the nutrient credit exchange (Senate Finance Committee, 2011).

Early planted cover crops must use specified seed types (winter rye, winter wheat, winter barley, triticale, or winter oats). The density of planting is also specified; typically two bundles per acre or three if seeds are aerially planted. To be 'early', in the Shenandoah SWCD, cover crops must be planted by October 5th. To qualify as an offset, cost-share funds cannot be used to implement this practice. Early planted cover crops cannot have nutrients applied prior to March 1st of the year following planting. An offset generated from early planted cover crops can be used for compliance in the year following early fall planting. The early cover crop must be removed between March 15th and May 15th of the following spring. Acceptable removal methods include mechanical, chemical, and grazing. The cover crop cannot be harvested.

The 15 percent nitrogen reduction on corn BMP requires that 85 percent or less nitrogen is applied to crops as recommended by a nutrient management plan. The offset applies to the year in which the corn is planted and harvested.

Unlike the previous two BMPs, the continuous no-till BMP must be implemented for a period of five years to qualify as an offset. A minimum of 60 percent of biomass residue must remain on the field and all specifications must meet NRCS standards for no-tillage. The credit would be available as an offset on January 1st the year after demonstration of the practice.

Agricultural land can be converted to a number of lower impact (i.e., less nutrient intense) land uses under the land conversion practice. A portion of a tract, such as a buffer, can be converted. This practice is eligible to be sold as a credit on January 1st the year following planting. The land use as of July 1, 2005 is considered the original condition of the tract for purposes of land conversion. Credits are generated on an annual basis as long as the land remains in the converted condition. Farmers may employ easements or similar instruments to ensure the duration of the land for offset contracts.

Nutrient Market Potential Studies

There are a number of key efforts that have been conducted to estimate the cost savings that may be attained with nutrient credit trading. The Chesapeake Bay Commission (2012) study is one of the largest efforts of this kind. The study considered the costs of implementing the TMDL across the entire watershed and evaluated a number of trading scenarios to estimate the least cost solution for each scenario in a policy analysis framework. The researchers found that constrained to in-basin trading, significant point sources could save 20 percent (approximately $78 million) on an annual basis if they were only allowed to trade with other significant sources. If they were further allowed to trade with agriculture non-point sources, the savings could reach 36 percent or $138 million annually.

To estimate the cost savings, the study developed an optimization model with the objective of finding the least cost solution under a number of scenario constraints. Importantly, the assumptions of the analysis included: trading constrained within state and further within basin, agriculture must first meet baseline requirements as outlined in individual state watershed implementation plans (WIPs), and trades include a transaction cost (38 percent). Transaction costs include the establishment of a legally binding contract between buyers and sellers which requires negotiation, approval, monitoring, enforcement, and insurance costs (Dudek and Wiener, 1996; McCann et al., 2005). The study relies on the Chesapeake Bay Watershed Model to derive the BMP efficiencies along with a 2:1 ratio for trading between an agricultural and point source (CBC, 2012).

The costs for significant point sources to reduce nitrogen and phosphorus are based on data from the Chesapeake Bay Program Office (2002), EPA (2008) analysis of nutrient reduction costs at municipal wastewater facilities, and are updated to 2010 values utilizing a construction cost index (CBC, 2012 Appendix A). The CBC study assesses thirteen agricultural BMPs (it should be noted that based on Virginia's current nutrient trading regulations many of these BMPs would have to be met in the baseline and would not be applicable for generating nutrient credits). The implementation costs associated with each of the agricultural BMPs are assessed based on data from EPA's draft cost estimates (EPA, 2012 draft). While the CBC utilized county-level data for land rental rates, all other costs associated with agricultural BMPs are a single unit value applied across the entire watershed (for more information see the CBC, 2012 Appendix B).

Overall, the CBC provides an important analysis illustrating the potential cost savings associated with trading. However, the actual costs saved along with the number of nutrient credits generated from agriculture are highly dependent on the actual costs of implementing BMPs. It is likely that the actual costs will vary between farms and that farmers' willingness to participate in a trading regime will vary along with those costs. There is a need for additional research on the heterogeneity of agricultural BMP costs and the nutrient reduction that can be achieved via trades based on a better understanding of those costs.

In 2012, the EPA developed a framework and applied it to the Chesapeake Bay TMDL implementation that included many of the same assumptions of the CBC study but further sought to assess the least cost solution when also considering ancillary ecosystem services (EPA, 2012). One notable difference in this study is that there were fewer agricultural BMPs included in the model (nine versus thirteen). The study also utilized the BMP effectiveness rates as derived from the Chesapeake Bay Watershed Model. The costs used in the EPA study were derived from previous cost collection activities including an analysis conducted in 2007 by the University of Maryland (Wainger and King, 2007) and an analysis prepared for the National Oceanic and Atmospheric Administration (Wieland et al., 2009). The costs were mainly estimated based on agricultural practices applicable in Maryland and do not have any further disaggregation for implementation beyond one unit value for the watershed.

The Department of Agriculture (USDA) (USDA ERS, 2013 forthcoming) is in the process of documenting an analysis which also considers the benefits of a nutrient trading regime to meet the requirements of the TMDL, but additionally considers alternative policy options. The effort evaluated the relative merits of an emissions tax and targeted nutrient reduction scenarios. The USDA developed an optimization tool to support the policy analysis; this effort improves on previous described models by including field-level data on agricultural practices (versus farm level data provided in the NASS Census of Agriculture which is used by other studies). The field-level data is a product of a USDA Conservation Effects Assessment Project and is not publicly available. Similar to the other TMDL studies, the USDA analysis relies on average costs at the watershed level. The results of this analysis are expected in 2015.

Thus far, trading in Virginia or the other jurisdictions has not been very successful in terms of a participation of traders and number of trades between regulated sources and farmers (Ribaudo, 2012). The lack of robust trading, and in particular the availability of credits for sale by farmers, indicates that the factors farmers consider to provide credits are not fully understood. All of these efforts on nutrient credit trading to implement the TMDL have broadened the understanding of the potential cost efficiency that may be attained by a trading regime; however, the lackluster trading signals that there are barriers to trading that have not yet been fully explored.

The barriers associated with implementation costs based on heterogeneity from field to field may have led to an overestimation of the number of farmers willing to participate and generate credits. There is generally a lack in understanding in the field-level costs of agricultural BMP implementation and this information would move the state of knowledge forward (Ribaudo, 2013). This case study will estimate the heterogeneity in field-level costs in the Shenandoah SWCD of Virginia. More importantly, this analysis will be used to estimate the potential nutrient pollution reductions that can be achieve meeting baseline conditions and installing tradable BMPs in the Shenandoah SWCD. This analysis will contribute to the understanding of why trades are lacking in the Virginia market and help form better policy to improve the market design.

CHAPTER THREE: FIELD-LEVEL COST HETEROGENEITY ANALYSIS

Background

The United States leads in the application of water quality trading programs (Shortle, 2012). However, trading in nutrient markets across the country has been "strikingly" low (Fisher-Vanden and Olmstead, 2013). Farm physical features (e.g., soil type) and external factors (e.g., weather) influence agricultural production and nutrient runoff requiring highly site-specific information to determine an optimal cost-minimization strategy (Lichtenberg, 2004). This suggests there is a significant degree of heterogeneity in the costs of agricultural nutrient abatement, in particular as the geographic scale is reduced (Shortle, 2012).

Wossink and Osmond (2002) evaluated BMPs in North Carolina and found empirical evidence of this heterogeneity for three regions in the same basin; they suggested that these differences should be accounted for in policy design to ensure effective implementation. There is empirical support for the need to increase the understanding of costs of implementing BMPs to increase farmer participation in voluntary BMP programs (Afari-Sefa et al., 2008). Knowledge-intensive field-level information is critical to encouraging sustainable farming (Tilman et al., 2002). Detailed data at this scale will also better inform policy outcomes (Antle et al., 2014). To estimate the magnitude of nutrient reductions (via nutrient credits) that can be expected from agriculture as part of the entire strategy for meeting the TMDL at the lowest cost, additional analysis of the heterogeneity in field-level costs of agricultural BMPs is needed.

There have been a number of efforts that consider the least cost solution to implementation of the Chesapeake Bay TMDL by evaluating the cost efficiency potential of trading nutrient credits between point sources and non-point sources (CBC, 2012; Wainger et al, 2013; USDA, 2013 forthcoming). Each of these studies assumes agricultural BMP costs based on state and county level average costs. The heterogeneity in field-level costs of BMPs influences the number of farmers willing to implement BMPs and the quantity of nutrients that can be reduced through agricultural BMPs.

The state of Virginia has a cost-sharing program to encourage the implementation of BMPs. Its 47 Soil and Water Conservation Districts (SWCD) receive allocations to administer the State's financial and technical support programs for agricultural BMPs (DCR, 2013). Through their cost-share program, Shenandoah SWCD is notable for documenting the actual field-level costs of implementing BMPs. An analysis of the heterogeneity in BMP costs in the Shenandoah SWCD jurisdiction is presented below.

Datasets

To assess the heterogeneity in field-level costs requires access to detailed cost information from individual farmers on the implementation of BMPs. Based on data availability, the scope of the current analysis is limited to the Shenandoah SWCD in the state of Virginia. The present analysis uses a multi-tiered dataset developed from information provided by the Shenandoah SWCD in June of 2014 (Shenandoah SWCD, 2014a).

The State of Virginia maintains a database of the agricultural BMP projects that receive financial assistance from the state. The database, the Virginia Agricultural BMP and CREP Database Query Form ("VA BMP Database"), provides the following relevant information for each project:

- BMP name,
- jurisdiction name and hydrologic unit (a.k.a., watershed segment);
- extent installed (e.g., linear feet of fence);
- acres benefited;
- average buffer width;
- animal type, animal count, and animal waste treated;
- conservation effectiveness factor;
- program type(s);
- total cost, state cost-share payment, and other payments;
- design lifespan and completion date (DCR, 2014b).

The database provides extensive information on a number of BMP projects and their locations across the State. There are 179,562 distinct records for jurisdictions across the state. The database allows an analysis of how much cost-share funds are being allocated for each type of BMP and in which counties or watershed those funds are being dispensed. Finally, the VA BMP Database can be used to estimate the number of acres benefited and to approximate the quantities of nutrients reduced as a result of the projects.

There are two issues to consider with the VA BMP Database: one factor that limits its representative quality is that only farmers receiving direct payments, cost-share, or tax incentives from Virginia are included (DCR, 2014b). A survey of farmers in Virginia found that the majority that had installed BMPs had done so without cost-share assistance (Benham et al., 2007). The BMPs considered in the survey were largely erosion reduction mechanisms and do not perfectly align to the nutrient reducing BMPs in the present analysis; however, the survey does acknowledge the many farmers that install BMPs without cost-share assistance. To the extent that farmers install BMPs without cost-share assistance, those projects will not be captured in the VA BMP Database.

The second issue with the VA BMP Database, and of particular relevance to this study, is that the costs are not 'true costs'. The majority of cost share funds are distributed based on flat rates (DCR, 2014a). The VA BMP Database's estimated costs are the flat rate multiplied by the number of acres for the particular project. This does not provide any insight into the heterogeneity of actual costs for implementing the BMPs.

A comprehensive literature review was conducted to identify a source of actual field-level costs for BMP implementation in the state of Virginia. This research did not reveal a suitable resource. Additionally, as part of the overall research and specifically to locate field-level costs, elicitation of experts and practitioners was conducted. Table Five provides the position, affiliation, and whether or not the individual provided data (See Appendix 2 for Institutional Review Board Human Subjects Research Determination Form). The elicitation exercise was targeted to include known experts in the field of agricultural BMPs and practitioners working closely with farmers to implement BMPs in the state of Virginia. The interviews included representatives from the federal government (USDA, USGS, EPA), state government (VA DCR), local SWCD offices, academia, and private industry.

Table 5. Expert and Practitioner List

Position	Affiliation	Data Provider
Associate Director for Science, Analysis and Implementation	U.S. Environmental Protection Agency, Chesapeake Bay Program Office	No
Senior Extension Agent Agriculture and Natural Resources Certified Professional Agronomist	Virginia Tech University, Virginia Cooperative Extension	No
District Manager	Shenandoah SWCD	Yes
Budget and Accountability Team Leader	U.S. Environmental Protection Agency, Chesapeake Bay Program Office	Yes
Extension Economist Farm Management	Virginia Tech University, Virginia Cooperative Extension	No
Research Physical Scientist	U.S. Geological Survey	No
Senior Conservation Specialist	Lord Fairfax SWCD	No
Soil and Water Conservation District Liaison	Virginia Department of Conservation and Recreation, Division of Non-point Pollution Prevention	No
Conservation Specialist	Culpeper SWCD	No
Senior Economist	USDA, Economic Research Service, Conservation and Environment Branch	No
County Executive Director	Farm Service Agency Shenandoah & Northern Counties	No
Research Professor	University of Maryland Center for Environmental Science	No
Director and Senior Economist	RTI International, Ecosystem Services Research	No

The interviews provided excellent insight into the field of agricultural BMPs, agricultural economics, and nutrient markets. The EPA Chesapeake Bay Program Office provided a database on the average costs of BMP installation, operations and maintenance (EPA, 2013 draft). These costs and sources were quoted in the previous section’s discussion on BMPs (see Chapter Two). This data was used as a source of comparison to the field-level costs. Most sources for economic evaluation of the Chesapeake Bay TMDL decision and potential for markets have used this database (Van Houtven, personal communication 2014; Wainger, personal communication 2013; Ribaudo, personal communication 2013).

All of the interviewees were asked if they were aware of a source of field-level BMP costs and if they were aware of anyone doing research in this area. Only the Shenandoah SWCD director was able to suggest a source of actual field-level costs. The Shenandoah SWCD records the actual costs of BMP implementation based on farmer receipts. This information is aggregated in an excel-based query system. Additionally, the office maintains the hard copy of receipts for each project.

The data contained in cost files is of a proprietary nature since it relates to the amount that farmers have paid for installing BMPs and includes personally identifiable information such as farm location, name, and social security number. It is of the utmost importance to the Shenandoah SWCD to protect this information and to ensure that they remain trusted partners by farmers. To advance the current line of research, the Shenandoah SWCD Board of Directors decided to allow access to the actual cost data with some caveats and limitations, such as removing farmers’ personally identifiable information from records prior to providing electronic data for the study and only allowing access to physical files at the SWCD office (see Appendix 1).

The analysis of data includes output of the level of heterogeneity and insights on the factors that influence cost without attributing any specific costs to particular farms or identifiable features such as specific farm size, location, or farmer name. The two levels of data are described below.

Aggregated Cost Database

Shenandoah's aggregated cost database output provides six (6) years of data on BMP projects implemented in the SWCD through the Virginia Cost-Share Program. The parameters provided for each BMP are listed in Table Six.

Table 6. Shenandoah SWCD Actual Field-level Cost Data Parameters

Parameters		
County	Total Approved Cost Share	Completion Date
Hydrologic Unit	Total Estimated Cost	Extent Installed
Practice	Distance To Stream	Extent Benefitted
Practice Lifespan	Stream Bank Protected	Total Actual Instance Cost
Extent Authorized	Waste Treated	Total Actual Cost Share Payment
Primary Animal Type	Area Buffer Restored	Tax Credit Amount Issued
Primary Animal Count	Average Buffer Width	Other Funding Amount & Sources

There are 1,923 individual records in the database installed between 2008 and 2014. Each record represents a specific project. There may be multiple projects on the same farm and even the same field. The database does not allow for analysis of precise locations of projects. It is not possible to derive if farms (or fields) have one or more BMPs installed. Rather, the database can only be used to look at each of the BMP projects individually.

Table Seven lists the 23 BMPs and the number of records for each. Not all BMPs in the database are included in the present analysis; those in bold in are included. The remainder are eliminated from consideration for a number of reasons including: there are too few records (less than ten), key parameters (e.g., actual costs) are not included on the particular BMP, the primary purpose of the BMP is not related to nutrient reduction, or the BMPs are not eligible within the framework of the Virginia nutrient trading regulations (either required in the baseline or can be used as a credit).

Table 7. BMPs in Shenandoah SWCD Database

BMPs	Count
1. CREP Riparian Forest Buffer Planting	**61**
2. CREP Grazing Land Protection	28
3. CREP Streambank Protection	15
4. CREP Grass Filter Strips	5
5. Aforestation of erodible crop and pastureland	13
6. Woodland Buffer Filter Area	8
7. Livestock Exclusion with Riparian Buffers for TMDL Implementation	**11**
8. Livestock Exclusion with Reduced Setback for TMDL Implementation	4
9. Livestock Exclusion with Reduced Setback	7
10. Sidedress Application of Nitrogen on Corn	8
11. Manure Application to Corn Using Pre-application Nitrate Test	116
12. Permanent Vegetative Cover on Cropland	**83**
13. Permanent Vegetative Cover on Critical Areas	3
14. Small Grain Cover for Nutrient Management	**601**
15. Stream Exclusion With Grazing Land Management	**30**
16. Alternative Water System	17
17. Harvestable Cover Crop	**806**
18. Legume Cover Crop	16
19. Streambank Protection (fencing)	8
20. Animal Waste Control Facilities	**53**
21. Extension of CREP Watering System	6
22. Loafing Lot Management System	13
23. Composter Facilities	11

The seven BMPs included in the analysis are cross-walked to the categories of BMPs discussed in the background section in Table Eight below. After a small number of records were deleted due to incomplete information, the final number of project records included in the current analysis is 1,639.

Table 8. Actual Cost Database BMPs crosswalked to BMP categories

BMP Category	Actual Cost Database BMP Practice Name	Actual Cost Database BMP Practice Code
Nutrient Management	None	None
Buffer Zones	CREP Riparian Forest Buffer Planting	CRFR-3
Physical Exclusions	Livestock Exclusion with Riparian Buffers for TMDL Implementation	LE-1T
	Stream Exclusion with Grazing Land Management	SL-6
Cover Crops	Permanent Vegetative Cover on Cropland	SL-1
	Harvestable Cover Crop	SL-8H
	Small Grain Cover for Nutrient Management	SL-8B
Tillage Management	None	None
Land Conversion/ Conservation	None	None
Manure Management	Animal Waste Control Facilities	WP-4

As Table Eight shows, there are a number of categories that are not represented by BMPs in the current analysis and the heterogeneity in costs for these practices is not assessed. Nutrient management is not included in the aggregated cost database. The Shenandoah SWCD has provided cost-share assistance for Nutrient Management Plan Writing and Revision (code NM-1), Nutrient Management Plan Writing and Revisions (code NM-1A), and Nutrient Management Plan Implementation and Record Keeping (code NM-2) for 375 instances since 2008 (DCR, 2014b). This suite of practices was not included in the aggregated database because the district does not keep detailed records of actual costs (Megen Dalton, personal communication).

There are no tillage minimization practices included in the Shenandoah SWCD aggregated database. Since 2008, there has only been one instance of a tillage minimization practice - Continuous No-Till Forage Production System (code SL-15B) in the Shenandoah SWCD (DCR, 2014b). According to the DCR Query System (2014b) there were no instances of land conversion/conservation in the Shenandoah SWCD since 2008.

Hard Files on Actual Costs

The total population of estimates (1,639) is used to estimate the field-level heterogeneity in costs. The Shenandoah SWCD also maintains physical file records on the projects. These files include the paper receipts for individual BMP projects. The information in the physical files is aggregated in the spreadsheet that is used to estimate costs. The physical files provide information on the factors that influence the costs on individual farms. Reviewing these files increases insights into the underlying driver of the heterogeneity in costs. It was not feasible to review all of the physical files due to the administrative burden it would place on the Shenandoah SWCD office in making those available and ensuring proprietary information is secured.

A sampling approach was therefore designed to review a subset of the physical files. This information is used to supplement the aggregated cost database of all projects in the SWCD. The sample was designed to include at least the minimum cost, median cost, and maximum cost instance for each BMP. Costs in the first and third quartile were also selected for the BMPs with larger counts (harvestable cover crop and permanent vegetative cover crop). Initially, 48 files were selected, a few were not locatable and many of the harvestable cover crop files did not have a substantial amount of data. A total of 25 files were ultimately reviewed in detail and provide insight into the costs of individual components of BMP installations. This will be discussed in greater detail in the results section.

Approach to estimate heterogeneity in field-level costs

This dissertation's principal thesis is that the heterogeneity in actual field costs of BMPs is influencing farmers' willingness to participate in nutrient trading. This section describes the approach to assess heterogeneity in the data. Previous efforts to evaluate agricultural BMP costs have focused on the average cost. The average is a measure of the central tendency of a dataset and does not provide much information about the individual values within the data (Norusis, 2006). To estimate the heterogeneity in field-level costs, the data was assessed for variability. There are a number of measures of variability that were used to consider the data including: interquartile range, variance, and the coefficient of variation.

To illustrate the heterogeneity in the cost data, a box and whisker plot - which shows the minimum, maximum, and median of the data - was developed for each BMP. The box and whisker plot also clearly indicates the interquartile range, the distance between the 25^{th} and 75^{th} percentile of the data, which is a good indicator of variation since it reduces the influence of outliers (Norusis, 2006). Variance is the most commonly used measure of variability (Norusis, 2006); a large variance indicates that the data is heterogeneous. Mean and standard deviation are common measures in descriptive statistics and are estimated for each of the BMPs. The most significant measure for the analysis of heterogeneity is the coefficient of variation. Unlike variance, the coefficient of variation is independent of unit and allows for the comparison of heterogeneity between BMPs.

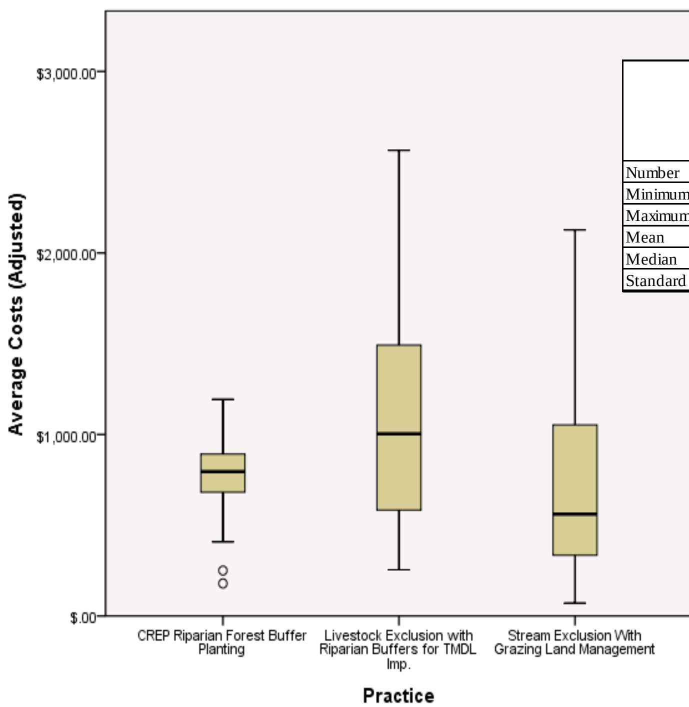
The descriptive statistics and measures of variance are estimated for each of the BMPs using Excel 2010. The box and whisker plots were created in SPSS 22. Variability is estimated for the eight BMPs provided in the Shenandoah SWCD aggregated database. The costs are estimated as current (2014) U.S. Dollars (USD). The Shenandoah SWCD aggregated database provides costs in current year terms (i.e., for a 2008 project, 2008 USD are displayed). To account for this and avoid under- or over-estimating heterogeneity in costs, all of the costs are updated to 2014 USD using inflation factors (USDA ERS Agricultural Services, Index for Prices Paid (USDA, 2011b) and updated with 2011 to 2014 Bureau of Labor Statistics price indices). The field-level factors and the results of heterogeneity based on the measures of variability will be discussed in next section.

Results

For each of the BMPs in the scope of this analysis, this section provides descriptive statistics for costs. Box and whisker plot diagrams are provided to illustrate the significant statistics and variance in costs of each of the BMPs. The detailed statistics are provided in Appendix 3. The physical file insights on factors that influence total cost are also described. Finally, a comparison of the heterogeneity in the BMPs is discussed.

Descriptive Statistics

Significant descriptive statistics are illustrated by box and whisker plots for each of the BMPs along with a table including: count, minimum, maximum, mean, median, and standard deviation. The forest buffer and two physical exclusions BMPs are grouped in Figure Five. The interquartile range is represented by the gold box and the median is shown by the dark black line. Fifty percent of the costs are above the median. For the CREP riparian forest buffer BMP, the median is $796 per acre and the box and whisker plot shows the middle fifty percent of costs are spread over an interquartile range of $892 per acre. In comparison, the livestock exclusion with riparian buffers for TMDL implementation has a median cost of $1,004 per acre. The box and whisker plot clearly illustrates the higher degree of variance for this BMP with a larger interquartile spread and significant difference between the minimum and maximum costs.



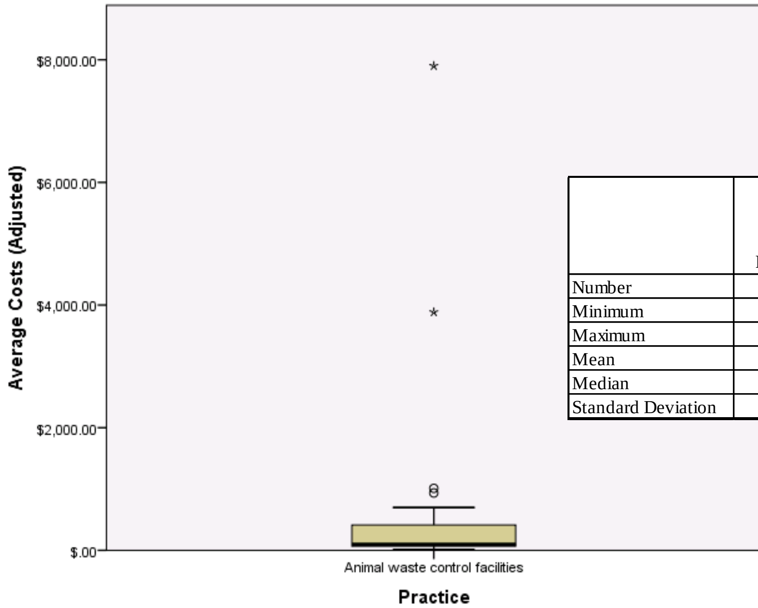
	CREP Riparian Forest Buffer Planting	Livestock Exclusion with Riparian Buffers	Stream Exclusion with Grazing Land Management
Number	60	11	30
Minimum	$179	$255	$71
Maximum	$1,194	$2,566	$2,127
Mean	$760	$1,114	$761
Median	$796	$1,004	$562
Standard Deviation	$178	$713	$527

Figure 5. Forest Buffer, Livestock Exclusion, and Stream Exclusion BMP Box and Whisker Plots

The livestock exclusion with riparian buffers practice (code LE-1T) requires fencing to exclude livestock, the installation of alternative watering structures, and installation of a riparian buffer with a minimum width of 10 feet (DCR, 2014a). Stream exclusion with grazing land management (code SL-6) does not require installation of a riparian buffer (DCR, 2014a) and is therefore expected to have a lower cost. Depending on the shape of a field and water frontage, significant differences in the linear feet of fencing required to benefit the same acreage may be necessary.

The stream exclusion with grazing land management BMP has a spread similar to that of livestock exclusion. The median cost is $562 per acre and the interquartile range shows that costs are more skewed above this value than for the other two BMPs. The average cost for stream exclusion with grazing land management is $761 per acre; this value is considerably higher than the median due to the skewness of observations on the high side.

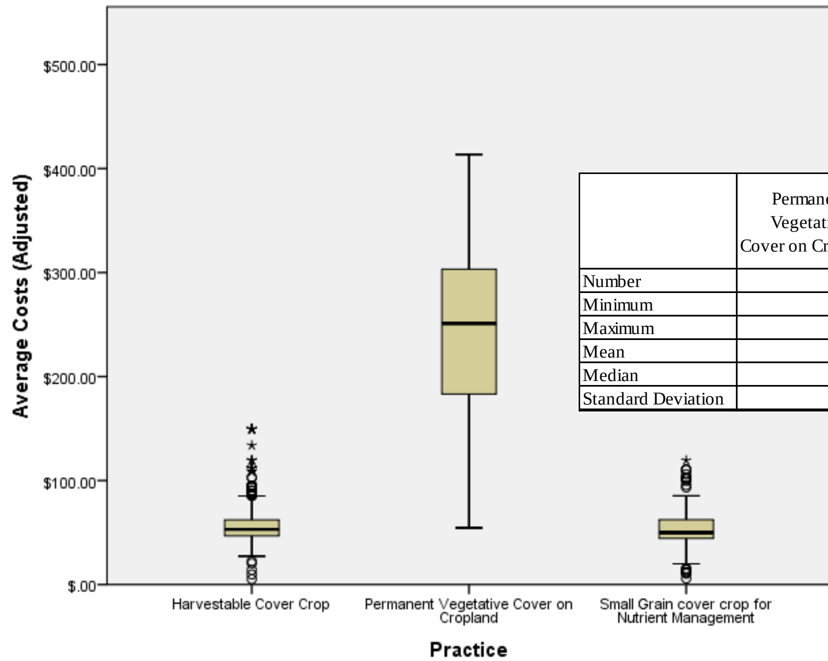
Figure Six shows the box and whisker plot for animal waste control facilities. This BMP has a number of outliers including one facility which cost nearly $8,000 for one ton of waste treated and another that was nearly $4,000 per ton. These outliers were removed from further analysis to better capture the costs associated with the majority of projects (96 percent).



	Animal Waste Control Facilities
Number	50
Minimum	$9
Maximum	$1,011
Mean	$215
Median	$95
Standard Deviation	$237

Figure 6. Animal Waste Control Facilities BMP Box and Whisker Plot

Figure Seven displays the box and whisker plots for harvestable, permanent, and small grain cover crop BMPs. Harvestable cover crops have a median cost of $53 per acre. The variance for this BMP appears much smaller in the box and whisker plot with a standard deviation of only $16 per acre. In contrast, permanent vegetative cover on cropland is a large range with a median cost of $251 per acre and a standard deviation of $88 per acre. The small grain cover crop for nutrient management BMP has similar cost characteristics to the harvestable cover crop BMP. The median cost is $50 per acre with a standard deviation of $15 per acre.



	Permanent Vegetative Cover on Cropland	Harvestable Cover Crop	Small Grain Cover for Nutrient Management
Number	83	802	$601
Minimum	$54	$5	$6
Maximum	$413	$149	$119
Mean	$240	$56	$53
Median	$251	$53	$50
Standard Deviation	$88	$17	$15

Figure 7. Cover Crop BMPs Box and Whisker Plots

Cost Drivers

Insights on what factors drive total cost for each of the BMPs were derived from the physical files. The sample size is relatively small (25) and therefore the results are included to provide context rather than conclusive output. For forest riparian buffers, four files were reviewed to assess the factors that drive costs and the heterogeneity that is observed in those costs. Based on these specific field-level projects, 97 percent of costs are for the purchase and installation of trees. Other costs incurred are for pest management to ensure that the trees will survive. All of these projects used seedlings. The variety of tree species differed between projects and likely led to the large variation in costs. The location of each site and the cost of bringing seedlings in may have also influenced the cost; the installation, seedling, and transport costs were not disaggregated in the files. According to the Virginia DCR code for forest riparian buffers, tree species and density is dependent on the environmental needs of the site with a minimum tree density of 150 trees per acre (DCR, 2014a).

Three projects for the livestock exclusion with riparian buffers practice were evaluated in detail. All of these projects had exclusion fencing and one also had a water crossing for livestock. The cost per acre of stream exclusion and installation of a water trough ranged in these projects from $240 to $2,012. There does appear to be an economy of scale whereby a larger project has smaller unit costs of installation and materials. One of the projects, however, has the stream crossing which greatly increases the overall cost of the project.

The price for installation of a water trough differed greatly among the three projects reviewed in detail. For one project, the cost to install the water trough was 28 percent of the total project cost while for the other two projects this amounted to only about four percent. Also differing are the cost of fencing – depending on 3-strand versus 5-strand – and fence installation which ranged from 15 to 30 percent of the total project costs. Overall, there is a great deal of variability in the materials used, whether or not a fence charger was needed, if equipment was rented or the farmer already had it onsite, and on the difficulty in accessing water for alternative water source. Installation costs varied based on the soil type, in particular, the rockiness of the site which incurred greater drilling and fence installation costs.

For the stream exclusion with grazing land management BMP, three projects were reviewed in detail. These stream exclusion projects with alternative watering sources ranged in total cost from $35,000 to $77,000. The highest proportion of cost for all of these projects was the equipment and installation of watering facilities which includes a water trough and piping of water to the surface. The cost for this component (compared to fencing material and installation) made up from 70 to 90 percent of the total project costs. The heterogeneity in costs for this practice appears to be driven largely by the variance in costs of providing water for livestock which is relative to the type of soil and depth of well needed to access water.

Files for animal waste control facilities were not reviewed. Four permanent vegetative cover crop projects were looked at in detail. The total cost for these projects were from $1,500 to $2,500. The type of seed that was chosen varied and the cost of seed were anywhere from 15 percent of the total project costs to 64 percent. Other cost components include prepping the land for planting, herbicide, fertilizer and soil testing. One project had substantially higher land preparation costs than the others signifying it as an outlier. Generally the major factors influencing price for this practice are the types of seeds and the readiness of the site for planting.

Three harvestable cover crop projects were evaluated in detail. The three projects each used a different mix of seed; with one using only barley, one using rye, and the third using a mix of barley, clover and radish. The cost of each project per acre differed with two being similar at $64 and $69 per acre while the third was $130 per acre. The total cost for the projects ranged from $1,628 to $9,089. The proportion of the cost due to seed versus planting also differed with type of seed. While one project's total costs were comprised of seed at 38 percent with the remainder being planting costs, the other two projects were mainly seed costs (at 64 and 70 percent). The type of seed chosen in harvestable cover crop will influence the price that can be fetched for crops; this will influence a farmer's decision on which seeds to plant.

Heterogeneity

A significant measure of heterogeneity is the coefficient of variance. This measure allows comparison between BMPs since it is unitless. Figure Eight below shows the coefficient of variance for each of the BMPs. The animal waste control facilities BMP has the highest coefficient at 110 percent.

Forest riparian buffers have a coefficient of variance of 23 percent; this is the lowest variance observed in any of the BMPs. Both types of livestock exclusion – with riparian buffers and with grazing land management – have very high variance with coefficients of variance of 64 and 69 percent respectively. The three cover crop practices have similar coefficients of variance with permanent vegetative being 37 percent, harvestable at 30 percent, and small grain being 28 percent.

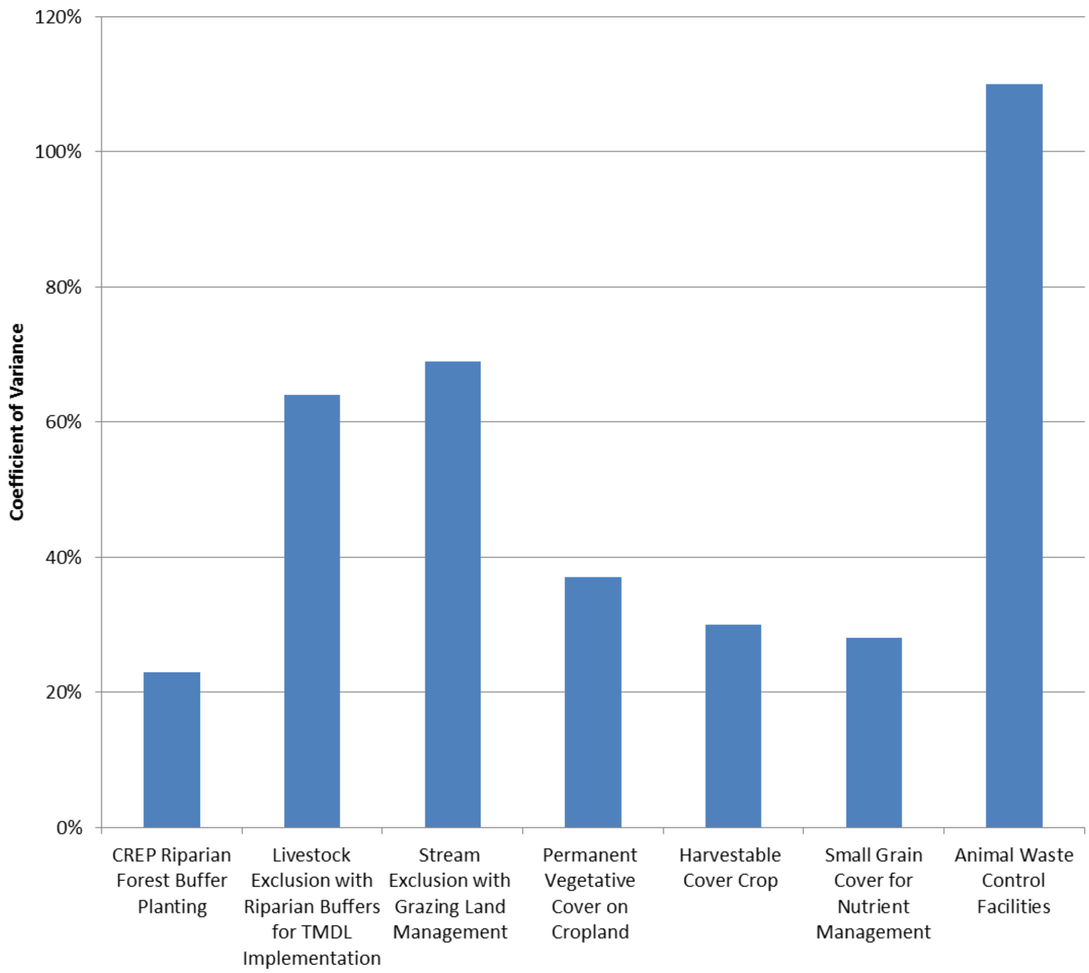


Figure 8. BMPs' Coefficients of Variance

Discussion

The descriptive statistics and measures of variance for the seven BMPs assessed indicate that the costs of installation vary widely. The analysis of physical files on a sample of the BMP projects show there are several factors that influence the costs including type of soil, seeds chosen for cover crops, seedlings chosen for riparian buffers, water frontage for fencing, and equipment available on the farm. Evaluating farmer willingness to participate in nutrient trading without accounting for the heterogeneity in costs is likely to result in errors.

The high amount of heterogeneity evidenced by the coefficients of variance was expected. The practices that have the least number of factors (e.g., seeds and planting) have the least heterogeneity. For example, forest riparian buffers are observed to have the smallest coefficient of variance. The installation costs are associated with only three factors: seedlings, land preparation, and planting. This BMP requires a minimum density of plantings; therefore, there is not a great deal of variation in the quantity of materials needed. One factor that does influence the variance in cost is the type of seedlings purchased and this is determined based on the environmental condition of the site.

The high variance in physical exclusions was expected. This practice has at least eight factors (e.g., fence, pipe, water trough, drilling, land prep, soil type, water depth, and stream frontage) and is far more complex than riparian buffers. The fencing materials needed for one field that is the same acreage as another field will not necessarily be the same depending on how much river frontage there is and other natural features of the landscape. Even more complex, and variable, is the materials and labor to access water for the alternative watering source. This cost factor greatly influenced the projects for physical exclusions that were analyzed in detail, with per acre costs ranging from $240 to $2,012. Rocky soil, length of fencing, accessibility of water, and availability of equipment on site all influence the cost of the physical exclusion practices.

Cover crops had a high degree of variability, though less than physical exclusions and more than buffer zones. One might anticipate that cover crops have limited variance since the requirements of any cover crop installation requires seed, planting, herbicide, and fertilizer. However, based on the detailed analysis, there was a greater amount of variability in the types and costs of seeds used for these practices than initially expected.

It is useful to consider how the degree of variance identified in the observed costs of installation for the seven practices compares to the average data in the EPA cost database. This database, as previously mentioned, serves as the cost data for multiple economic analyses of the potential for nutrient trading in the Chesapeake Bay watershed. Table Nine provides the mean and median observed for each of the BMPs as well as the comparable mean for the practice in the Chesapeake Bay Program database.

Table 9. Comparison of Observed Mean and Median BMP Cost to Chesapeake Bay Model Data

	Best Management Practices						
	CREP Riparian Forest Buffer Planting	Livestock Exclusion with Riparian Buffers for TMDL Implementation	Stream Exclusion with Grazing Land Management	Permanent Vegetative Cover on Cropland	Harvestable Cover Crop	Small Grain Cover for Nutrient Management	Animal Waste Control Facilities
Mean	$760	$1,114	$761	$240	$56	$53	$215
Median	$796	$1,004	$562	$251	$53	$50	$95
Chesapeake Bay Mean	$838	N/A	$291	$120	N/A	$120	$185

The average cost of forest riparian buffers at $760 per acre can be compared with the value in the Chesapeake Bay Program database of $838 per acre (EPA, 2013 draft).

Initially, looking at these two numbers may lead one to think that they are not that different and the EPA value may even overestimate the cost of installation of forest buffers. However, the median cost of installation observed is $796. Fifty percent of all projects in the Shenandoah SWCD incurred costs higher than this value. If modeling a farmer's willingness to participate in a program based on a cost that is less than the actual cost, there is likely to be an overestimation of participation. If heterogeneity is not accounted for in the simulation of trading, there will be nearly a 50 percent overestimation of total farmer participation in the market.

The average cost of Stream Exclusion with Grazing Land Management (SL-6) at $761 per acre can be compared with the value in the Chesapeake Bay Program database for stream exclusion with fencing estimated at $291 per acre (EPA, 2013 draft). Based on the box and whisker plot, the majority of observed costs are greater than $291 and using this EPA estimate would grossly underestimate the cost of fencing installation.

Referring back to the Chesapeake Bay Program Office estimate of $109 for permanent vegetative cover crops (EPA, 2013 draft), one can interpret that more than 50 percent of actual installation costs in the Shenandoah SWCD have a greater cost (median observed cost is $251). If it is assumed that the cost of installation is $109, there would be considerable error in the number of Shenandoah farmers willing to participate in trading schemes based on this assumption. For small grain cover crops, the Chesapeake Bay Program Office estimate is $120 per acre which is more than double the observed mean of $53; the maximum observed cost is actually $119. In this case, the cost is overestimated and would likely lead to a model that underestimates the number of farmers willing to provide this BMP. In the Shenandoah SWCD, this BMP has the second highest number of projects (601) likely based on the low cost.

The animal waste control BMP is estimated to have a cost of $185 by the Chesapeake Bay Program Office. The mean observed in the Shenandoah SWCD is $215; however the median observed cost is $95. There is significant heterogeneity in the cost of this BMP and based on the box and whisker plot, the majority are more than the CBPO estimate. A simulation of farmer willingness to participate in the nutrient trading program by implementing an animal waste control BMP would be overestimated using the CBPO cost.

The average value in the Chesapeake Bay Program database is less than most of the observed averages in the Shenandoah SWCD. More significant than this difference alone, is that the median observed values are greater than the database mean. This indicates that fifty percent of actual project costs exceed the estimated value in the Chesapeake Bay Program database. The results of the analysis highlight the importance of accounting for heterogeneity in field-level costs in the estimation of farmers' willingness to provide nutrient reductions.

The findings of the analysis of heterogeneity in the actual field-level costs of BMPs have significant implications for the implementation of the TMDL. Specifically, previous estimates of the potential benefits of nutrient trading (CBC, 2012; Wainger et al, 2013; USDA, 2013 forthcoming) are likely to have overestimated farmer willingness to participate in nutrient trading. Nearly half of observed BMP costs in the Shenandoah SWCD had costs which exceeded the average estimates provided by the CBPO database.

The results of the present analysis show the significant extent of heterogeneity in the BMP costs and justify the need to consider a range rather than an average cost.

The overestimation of farmer willingness to participate in nutrient trading impacts both estimates of the total cost of TMDL implementation and the state WIPs. Current understanding of farmer willingness to participate may influence states in how they plan to meet watershed implementation goals. The higher costs and heterogeneity in costs of BMPs will reduce the ability of the states to rely on agricultural BMPs under current conditions (whereby BMPs are voluntary and trading is constrained in-basin).

The present analysis highlights the need to understand actual field-level costs for agricultural practices in payment for ecosystem service programs and market-based trading regimes. This information can help to improve the design of these programs and allocate resources more efficiently. The present analysis contributes to the understanding of actual field-level BMP costs and the degree of heterogeneity in those costs. The field-level costs are used to simulate farmers' contributions to the reduction in nutrient pollution in the Chesapeake Bay from the Shenandoah SWCD. This analysis is described in the next chapter.

CHAPTER FOUR: NUTRIENT REDUCTION ACHIEVED BY SHENANDOAH SWCD AGRICULTURE CREDITS

Background

Wastewater treatment facilities in the Virginia Potomac watershed are required to reduce their annual load to 3.552 million pounds of nitrogen from 3.663 million (2009 baseline) by 2025 (ChesapeakeStat, 2014); a three percent reduction. They must reduce phosphorus loads by 169,000 pounds, a 39 percent change (436,000 in the 2009 baseline to 267,000 in 2025) (ChesapeakeStat, 2014). In addition, any additional capacity or new facilities must fully offset their entire wasteload (VDEQ, 2010). Wasteload allocation goals for individual treatment facilities in the state Watershed Implementation Plan are largely based on technically achievable concentration standards and plant design flow (Stephenson et al., 2010). It is likely that existing wastewater treatment facilities will be able to achieve compliance with point to point source trading alone (Stephenson et al., 2010).

Offsetting additional capacity and new treatment facilities will require the purchase of credits either from point sources or non-point sources. Wastewater treatment facilities expected costs to reduce a pound of nitrogen range from $15.80 to $47.90 (Senate Finance Committee, 2011). Urban stormwater costs to reduce nitrogen are even higher; the Chesapeake Bay Commission (2012) estimated that costs range from over $300 to nearly $1,000 per pound of nitrogen reduced depending on the BMP. Based on estimates like these, previous studies have indicated that agricultural BMP credits would be the preferred source of credits based on a lower cost of nutrient reduction (Faeth, 2000; Ribaudo, Heimlich, and M. Peters, 2005; Hanson and McConnell, 2008; Chesapeake Bay Commission, 2012).

In 2013, there were 184,752 nitrogen credit trades and 33,992 phosphorus credit trades in Virginia's nutrient credit trading exchange (VDEQ, 2013). All of the credits were supplied by wastewater treatment plants that operated at lower than allocated levels of nutrient loads. Nitrogen credit prices are currently pegged at $3.05 which is substantially less than estimated wastewater facility or stormwater costs. The robust point-non-point source nutrient credit market in the Chesapeake Bay watershed predicted by the aforementioned studies has not yet materialized. Assuming costs and demand from wastewater treatment facilities, the analysis of the agricultural nutrient credit supply side must not be correctly estimating willingness to participate.

Previous economic analyses of the trading potential have used average costs for agricultural BMPs found in the literature. A premise of this research is that the heterogeneity in field-level costs of agricultural BMPs influences the number of farmers willing to participate in a nutrient credit market in Virginia. A more robust analysis of actual, field-level costs was completed for the Shenandoah SWCD (detailed in Chapter Three). The analysis was used to assess the magnitude of voluntary contributions of nutrient load reductions from agriculture in the Shenandoah SWCD. This chapter describes the assumptions, datasets, methodology, and results of this analysis.

Assumptions

The Virginia nutrient credit exchange trading regulations (VDEQ, 2008) influence the constraints in assessing the magnitude of nutrient reductions in the Shenandoah SWCD. The regulations were described in detail in Chapter Two. Pertinent regulations include the need to meet the baseline before being eligible to trade and that the trade must occur within the sub-watershed. For the purposes of trading, the Shenandoah SWCD is only eligible to trade within the Potomac sub-watershed. As indicated in Figure Nine on the next page, the Shenandoah SWCD is in the Potomac River watershed.

For a field to be eligible to sell a credit based on a BMP, it must first have the following BMPs: soil conservation, standard cover crop, nutrient management, livestock exclusion (for pasture only), and a riparian buffer. Livestock exclusion is an expensive BMP as indicated in the analysis of actual costs in the Shenandoah SWCD (described in detail in Chapter Three). It is a priority BMP in the State of Virginia and cost-share is provided for 100 percent of installation costs (DCR, 2014a). Due to the full cost-share provided for this BMP, it is assumed that all fields that are pasture with a water body will install the livestock exclusion BMP and meet this baseline requirement.

Riparian buffers are another baseline BMP. The acreage of riparian buffers needed by all fields in the Shenandoah SWCD is unknown. Rather than farm acreage, this BMP is measured based on the water frontage on the farm and the width of the buffer (i.e., 35 or 100 feet). This information may be attainable via GIS-based analysis; however, it is outside of the scope of the current analysis.

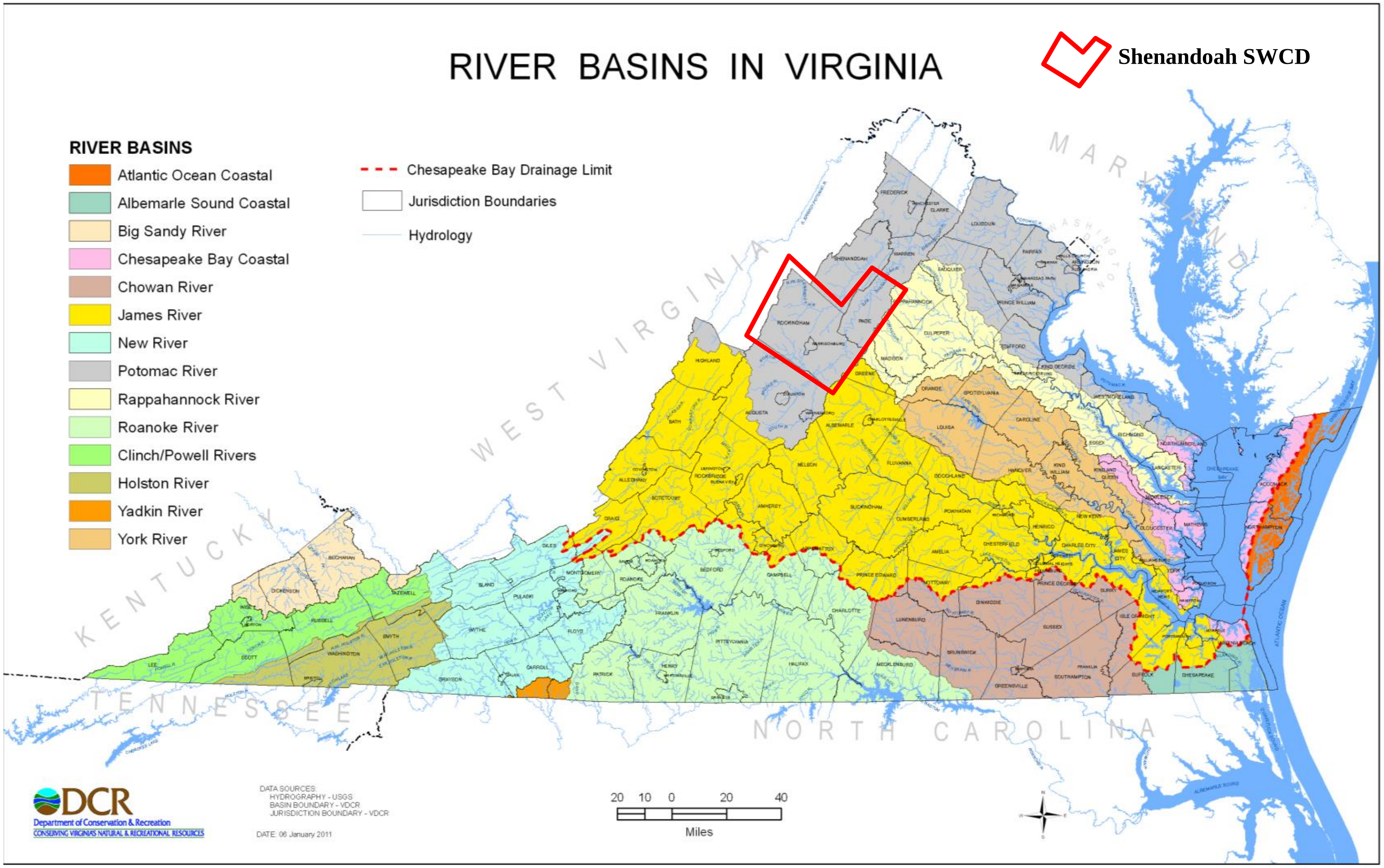


Figure 9. Virginia Watersheds and Counties (Source: DCR, 2011)

Due to the complex nature of estimating the land with this BMP installed, it is assumed that riparian buffers are not limiting in meeting the baseline (i.e., this BMP baseline requirement has been satisfied). The remainder of the BMPs of interest in the baseline and eligible for trading are assessed based on total net costs.

Datasets

The current analysis has a number of key considerations requiring data including: land use, BMP effectiveness, BMPs installed in the base case, and net costs of BMP adoption. The Base Case represents that current set of conditions that influence the amount of agricultural contributions of nutrients to the Bay. For example, the extent to which agricultural land is already managed with a BMP. Using the most recent data available, the Base Case represents 2013 for the Shenandoah SWCD. The sources for data and major assumptions are described in the text below.

Land Use

For the current analysis, the only major land use of concern is agriculture. Within that category there are several land use classifications that determine the eligibility of the land for a given BMP and the effectiveness of the BMP. In the Shenandoah SWCD, in 2013 agricultural lands were classified as: animal feeding operations, concentrated animal feeding operations, degraded riparian pasture, hay with nutrients, hay without nutrients, hightill with manure, hightill without manure, nursery, and pasture (CAST, 2013). Animal feeding operations and nursery lands do not have applicable baseline or trading BMPs and are therefore not considered further. Table Ten shows the 2013 acreage in each of the land use classifications in the Shenandoah SWCD.

Table 10. Agricultural Land Use in the Shenandoah SWCD

Land Use	Acres	Percent of Total Acreage
Animal feed lots	977	0.41%
Degraded riparian pasture	5,604	2.00%
Hay with nutrients	**56,582**	**24.00%**
Hay without nutrients	10,015	4.00%
Hightill with manure	**53,451**	**23.00%**
Hightill without manure	2,646	1.00%
Nursery	110	0.05%
Pasture	**106,478**	**45.00%**
Total	235,863	100.00%

For the current analysis, only significant land uses – characterized as greater than five percent of the total – are considered due to the limited impact that land uses with less than five percent would have on the results. Three major categories remain under consideration: hay (hay with nutrients), cropland (hightill with manure), and pasture (in bold in Table 10). One BMP, 15 percent nitrogen reduction on corn, is only applicable to cropland that is planted with corn. This makes it necessary to differentiate if cropland is planted with corn or any other crop. The 2012 Census of Agriculture (USDA, 2012) estimated there were 21,167 acres of corn planted in the Shenandoah SWCD. This value is used to derive the cropland in corn and cropland in other crop types. Table 11 shows the significant land uses considered in the current analysis.

Table 11. Agricultural Land Use in the Shenandoah SWCD in Current Analysis

Land Use	Acres	Percent of Assessed Acreage	Percent of Total Agricultural Lands
Hay	56,582	26%	24%
Cropland (Corn)	21,167	10%	9%
Cropland (Other)	32,284	15%	14%
Pasture	106,478	49%	45%
Total	216,611	100%	92%

BMP Effectiveness

Literature on the effectiveness of each of the BMP categories was described in Chapter Two. Effectiveness is often estimated as a percentage of nutrients reduced. The effectiveness of any BMP in reducing the nutrient load depends on multiple factors. Three factors are key in determining the eligibility of loads within the Chesapeake Bay paradigm: BMP, delivery factor, and land use. For the current analysis, the CAST model was used to derive the effectiveness of the BMPs for the Shenandoah SWCD with given land uses.

CAST is a scenario based model and has the latest land use and on the ground BMPs as reported by each of the states in the Bay watershed. To derive effectiveness in pounds per acre per year (lb/acre/yr), the tool was run with a 2013 scenario basis (the latest reported data in the model). Individual BMPs were then added for a single acre for each of the relevant land uses. Table 12 on the next page shows the reduction in nitrogen and phosphorus that are delivered[5] to the Chesapeake Bay for each of the BMPs on each of the relevant land uses. The assumptions are also provided in the table. The Virginia Department of Environmental Quality uses this tool to determine load reduced in Watershed Implementation Plans and for the purpose of assigning credits.

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5. Delivered is the quantity of nutrient load that actually reaches the Bay as opposed to the edge-of-field quantity of nutrient that leaves the farm field. Delivered is reduced by distance from edge-of-field to the Bay. The CAST model takes this delivery factor into account and is specified for the Shenandoah SWCD at large rather than the individual farm. For the purpose of meeting the BMP baseline and trading, this is the level of detail that is considered.

Table 12. BMP Effectiveness Values in the Current Analysis

	BMP	Nitrogen Reduced (lbs/acre/yr)	Phosphorus Reduced (lbs/acre/yr)	Source/Assumptions
Baseline	Nutrient Management	0	0	CAST doesn't have a nutrient management BMP; installation of actual practices recommended by the plan are what yield nutrient reductions
	Harvestable Cover Crop (Only Required On Cropland)	2.5	0	CAST cover crop, commodity, standard planting, barley
	Small Grain Cover Crop (Only Required On Cropland)	6.1	0	CAST, cover crop, standard planting (no harvest allowed), tricticale
Tradable	Early Planted Cover Crops	1.05	0	DEQ, 2008 based on CAST (used for trading eligibility)
	15% Nitrogen Reduction On Corn	2.60	0	DEQ, 2008 based on CAST (used for trading eligibility)
	Continuous No-Till	1.79	0.40	DEQ, 2008 based on CAST (used for trading eligibility)
	Land Conversion[6]			
	Cropland To Forest	10.91	0.81	DEQ, 2008 based on CAST (used for trading eligibility)
	Cropland To Hay	5.77	0.58	DEQ, 2008 based on CAST (used for trading eligibility)
	Cropland To Mixed Open (Fallow)	8.32	0.33	DEQ, 2008 based on CAST (used for trading eligibility)
	Hay To Forest	4.53	0.61	DEQ, 2008 based on CAST (used for trading eligibility)
	Hay To Mixed Open (Fallow)	1.94	0.13	DEQ, 2008 based on CAST (used for trading eligibility)
	Pasture To Forest	0.91	0.32	DEQ, 2008 based on CAST (used for trading eligibility)

6. Land conversion components do not sum, i.e., cropland to hay plus hay to forest does not equal cropland to forest. Values are as reported by CAST model.

Base Case BMPs

Fields in the Shenandoah SWCD already have a number of BMPs installed through the state and federal cost-share programs in the Base Case (2013). To understand the potential for additional BMPs and the extent to which farmers have already met the requirements in the baseline, the acreage of land already in these BMPs must be understood. The Virginia Department of Conservation and Recreation requires SWCDs to report BMPs receiving cost-share funding. The state manages a query system which allows users to identify BMPs for given time periods in the state, by county, and/or by SWCD (DCR, 2014b). To assess the BMPs that were installed or functioning in the Base Case, the query system was run for 2013 for all BMPs in the Shenandoah SWCD.

For the baseline BMPs, harvestable cover crop and small grain cover crop are single year BMPs and can be easily identified for 2013. Nutrient management has a design life of three years; for this BMP a query of 2011, 2012, and 2013 was completed. None of the tradable BMPs received cost-share funds in 2013. Table 13 shows the acreage in each of the relevant BMPs in 2013. Harvestable cover crop and small grain cover crop cannot be applied on the same acreage. Nutrient management can be applied on the same land as either cover crop BMP.

Table 13. Base Case BMP Acreage in Shenandoah SWCD in 2013 (Source: DCR, 2014b)

BMP	Acres
Harvestable Cover Crop	5,208
Small Grain Cover Crop	2,652
Nutrient Management	5,665

Next, the BMPs must be attributed to the relevant land uses. Table 14 reflects the major categories and crosswalks the land uses with the relevant BMPs.

Table 14. Land Use – BMP Crosswalk

Land Use	Harvestable Cover Crop	Small Grain Cover Crop	Nutrient Management	Stream Exclusion	Early Planted Cover Crops	15% Nitrogen Reduction on Corn	Continuous No-Till	Cropland to Forest	Cropland to Hay	Cropland to Mixed Open (fallow)	Hay to Forest	Hay to Mixed Open (fallow)	Pasture to Forest
Hay	√	√	√		√		√				√	√	
Cropland (Corn)	√	√	√		√	√	√	√	√	√			
Cropland (Other)	√	√	√		√		√	√	√	√			
Pasture				√									√

Data on the BMPs in the query database does not include the land use classification on which the BMPs are applied. To determine the acreage for each land use with a BMP installed in the Base Case, it is assumed that the BMPs are installed on each of the land use types in proportion to the acreage of that land use. None of the BMPs being considered in the Base Case applies to pasture. Table 15 below shows the acreage for each land use type in each of the relevant BMPs based on the calculation.

Table 15. Base Case BMPs by Land Use Type (Calculated)

Land Use	Acres	Percentage	Harvestable Cover Crop	Small Grain Cover Crop	Nutrient Management
Hay	56,582	51%	2,678	1,364	2,913
Cropland (Corn)	21,167	19%	1,002	510	1,090
Cropland (Other)	32,284	29%	1,528	778	1,662
Total	110,033	100%			

BMP Costs

To estimate the adoption of BMPs above the Base Case, the costs must be considered. The costs include capital or installation costs, operating costs, and opportunity costs. Research indicates that farmers consider the inherent risks associated, or opportunity costs, and account for those in financial decisions (Kurkalova, 2006). Chapter Three provided details on the analysis of heterogeneity in installation costs for the Shenandoah SWCD. Not all of the BMPs had cost data available. The operating and opportunity costs were not included in the Shenandoah SWCD data.

Table 16 provides the average capital, operating, and opportunity costs applied in the current analysis, in 2014 USD. The values are both from original research (the Shenandoah SWCD data) and the literature. Table 17 details the original source and assumptions used to estimate each of the costs. Table 16 also includes the design life for each of the BMPs. The annual operating and opportunity costs are converted to net present value over the entire design life of the BMP so that the values can be added for a single, net present value of the BMP. For net present value purposes, it is assumed that the interest rate is five percent to remain consistent with the Chesapeake Bay Program Office Cost Modeling assumptions (CBPO, 2013a).

Table 16. BMP Average Capital, Operating, Opportunity, and Total Costs (Source Information in Table 17)

BMP	Design Life (Yr)	Capital Cost ($/acre)	Operating Cost ($/acre/yr)	Operating Cost NPV ($/acre)	Opportunity Cost ($/acre/yr)	Opportunity Cost NPV ($/acre)	Total Cost (NPV $/acre)
Harvestable Cover Crop	1	$56	$0.00	$0.00	$0.00	$0.00	$56.00
Small Grain Cover Crop	1	$53	$0.00	$0.00	$0.00	$0.00	$53.00
Nutrient Management	3	$75	-$15.5	-$42.21	$0.00	$0.00	$32.79
Early Planted Cover Crops	1	$53	$0.00	$0.00	$13.33	$13.33	$66.33
15% Nitrogen Reduction on Corn	1	$0	-$5.53	-$5.53	$4.31	$4.31	-$1.22
Continuous No-Till	5	$339	$0.00	$0.00	-$40.00	-$173.18	$165.80
Cropland to Forest	15	$760	$0.00	$0.00	$59.00	$612.40	$1,372.40
Cropland to Hay	15	$260	$0.00	$0.00	$24.00	$249.11	$509.11
Cropland to Mixed Open (fallow)	15	$0	$0.00	$0.00	$59.00	$612.40	$612.40
Hay to Forest	15	$760	$0.00	$0.00	$35.00	$363.29	$1,123.29
Hay to Mixed Open (fallow)	15	$0	$0.00	$0.00	$35.00	$363.29	$363.29
Pasture to Forest	15	$760	$0.00	$0.00	$35.00	$363.29	$1,123.29

Table 17. Cost Data Sources and Assumptions

BMP	Capital Cost Source/Assumptions	Operating Cost Source/Assumptions	Opportunity Cost Source/Assumptions
Harvestable Cover Crop	Shenandoah SWCD original data analysis results	Capital expenditures include all annual costs; no maintenance costs	Crop is planted off-season so there is no opportunity cost
Small Grain Cover Crop	Shenandoah SWCD original data analysis results	Capital expenditures include all annual costs; no maintenance costs	Crop is planted off-season so there is no opportunity cost
Nutrient Management	VNRCS, 2011	Additional operating costs from VNRCS, 2011 less fertilizer savings from Virginia Soil and Water Conservation Districts, 2008	No yield reduction or land reduction so there is no opportunity cost
Early Planted Cover Crops	No data; assumes installation costs same as small grain BMP	Capital expenditures include all annual costs; no maintenance costs	No data; early planting reduces yield. From CAST (2013) model, difference in regular planting and early planting cover crop BMPs
15% Nitrogen Reduction on Corn	No data; assumes no capital expenditure for reducing nitrogen	No data; nitrogen savings based on Nehring (2011) lbs/acre nitrogen application in Pennsylvania (nearest location available), $/lb multiplied by 15% reduction	No data; assumes crop yield reduced by 7.3% multiplied by cropland rental rate based on Movafaghi (2013)
Continuous No-Till	No data; after Weiland (2009) assumes $40,000 expenditure for equipment divided by average farm size	Assumes operating costs cancel each other out. Additional herbicide costs and reduced labor, equipment costs. Based on Boyle (2006)	No data; assumes increase in yield based on Lee (2007) and (Schober, 2014)
Cropland to Forest	No data; assumes crops are harvested and forest planting costs are same as estimated for forest riparian buffer	No data; Assumes no maintenance	Cropland rental rate in Rockingham County, Virginia as reported by FSA, 2008
Cropland to Hay	No data; assumes crops are harvested and hay planting costs are same as estimated for vegetative riparian buffer	No data; Assumes no maintenance	Cropland rental rate in Rockingham County, Virginia less the rental rate of hayland as reported by FSA, 2008
Cropland to Fallow	No data; assumes no costs associated with leaving field fallow	No data; Assumes no maintenance	Cropland rental rate in Rockingham County, Virginia as reported by FSA, 2008
Hay to Forest	No data; assumes hay is harvested and forest planting costs are same as estimated for forest riparian buffer	No data; Assumes no maintenance	Hayland (assumes pasture rental rate) rental rate in Rockingham County, Virginia as reported by FSA, 2008
Hay to Fallow	No data; assumes no costs associated with leaving field fallow	No data; Assumes no maintenance	Hayland (assumes pasture rental rate) rental rate in Rockingham County, Virginia as reported by FSA, 2008
Pasture to Forest	No data; assumes forest planting costs are same as estimated for forest riparian buffer	No data; Assumes no maintenance	Pasture rental rate in Rockingham County, Virginia as reported by FSA, 2008

BMP Benefits

In addition to costs, there are monetary benefits that reduce the net costs of BMPs that must be considered. One is the value of cost-share assistance. The second potential benefit is income from the sale of nutrient credits. Table 18 displays the cost-share funds provided for each BMP. These values are the net present value of all cost-share funds for each BMP as reported by the Virginia Department of Conservation and Recreation (2014a).

Table 18 also shows the potential income from selling a nitrogen or phosphorus credit. Currently, the Virginia Credit Exchange Association (2013) has a fixed price for credits. A nitrogen credit is valued at $3.05 and a phosphorus credit is valued at $4.93. Based on the effectiveness data, the potential credit value per acre of BMP installed can be calculated as: effectiveness (lb/acre) x credit value ($/lb) = $/acre. The net present value for the entire design life of the BMP, assuming an interest rate of five percent, is provided in the table. The total potential benefit from cost-share assistance and nutrient credit sales is also shown in the table.

Table 18. Potential Benefits from Cost Share and Nutrient Credit Income

BMP	Design Life (Yr)	Cost Share ($/acre)	Nitrogen Credit ($/acre)	Nitrogen Credit NPV ($/acre)	Phosphorus Credit ($/acre)	Phosphorus Credit NPV ($/acre)	Total Benefits NPV ($/acre)
Harvestable Cover Crop	1	$20	$0.00	$0.00	$0.00	$0.00	$20.00
Small Grain Cover Crop	1	$15	$0.00	$0.00	$0.00	$0.00	$15.00
Nutrient Management	3	$12	$0.00	$0.00	$0.00	$0.00	$12.00
Early Planted Cover Crops	1	$40	$3.20	$3.05	$0.00	$0.00	$43.05
15% Nitrogen Reduction on Corn	1	$0	$7.93	$7.55	$0.00	$0.00	$7.55
Continuous No-Till	5	$350	$5.46	$23.64	$1.97	$8.54	$382.17
Cropland to Forest	15	$50	$33.28	$345.39	$3.99	$41.45	$436.84
Cropland to Hay	15	$50	$17.60	$182.67	$2.86	$29.68	$262.35
Cropland to Mixed Open (fallow)	15	$50	$25.38	$263.39	$1.63	$16.89	$330.28
Hay to Forest	15	$50	$13.82	$143.41	$3.01	$31.21	$224.63
Hay to Mixed Open (fallow)	15	$50	$5.92	$61.42	$0.64	$6.65	$118.07
Pasture to Forest	15	$50	$2.78	$28.81	$1.58	$16.37	$95.18

Approach

The methodology to estimate the nutrient credits supplied by agriculture in the Shenandoah SWCD requires land use evaluation, cost evaluation, and the development of scenarios. Each of the major steps is described below.

Land Use Evaluation

The total amount of agricultural land in each land use and the acreage that already includes a BMP is known. To derive the quantity of land available for additional baseline BMPs the difference in the total land use types less the quantity that is already installed in baseline BMPs is calculated. The total acreage of land that could potentially receive tradable BMPs is also calculated. Both of these quantities are the upper constraint on land availability and don't yet account for costs. Table 19 displays the calculated acres of land on which additional BMPs, either baseline or tradable, can be installed over the existing 2013 Base Case.

Table 19. Acres Available for Additional Baseline and Tradeable BMPs (Calculated)

BMP	Hay	Cropland (Corn)	Cropland (Other)	Pasture
Harvestable Cover Crop	52,540	19,655	29,978	0
Small Grain Cover Crop	52,540	19,655	29,978	0
Nutrient Management	53,669	20,077	30,622	0
Early Planted Cover Crops	56,582	21,167	32,284	0
15% Nitrogen Reduction on Corn	0	21,167	0	0
Continuous No-Till	56,582	21,167	32,284	0
Cropland to Forest	0	21,167	32,284	0
Cropland to Hay	0	21,167	32,284	0
Cropland to Mixed Open (fallow)	0	21,167	32,284	0
Hay to Forest	56,582	0	0	0
Hay to Mixed Open (fallow)	56,582	0	0	0
Pasture to Forest	0	0	0	106,478

Not all of the BMPs can be applied to the same field. A field can have either harvestable cover crop or small grain cover crop. It can have either cover crop type and have nutrient management and early planted cover crop. Figure 10 displays the BMPs that can be combined on cropland with distinct circles for those BMPs that are exclusive.

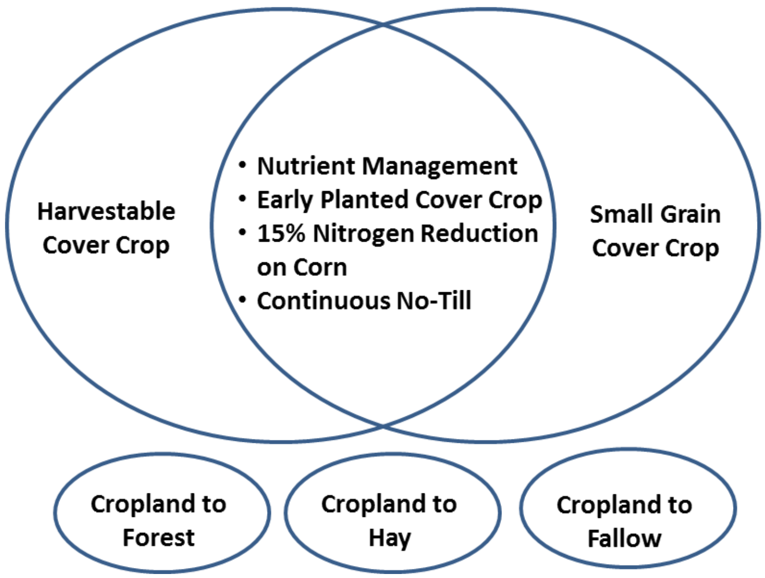

Figure 10. Potential to Combine BMP Applications (Original Graphic)

The quantities in Table 19 represent the total potential acres for each land use type. The actual quantity available for a BMP is reduced by the installation of a mutually exclusive BMP. For example, there are 19,655 acres of cropland for which 100 percent could be converted from cropland to forest which would leave zero acres available for harvestable cover crop or conversion of cropland to hay. Another example is if 100 percent of the cropland has nutrient management, there is zero available for a conversion, but 19,655 remains for either harvestable cover crop or small grain cover crop or a combination of the two. This is built into the model as a constraint to avoid double counting acres.

Cost Evaluation

To determine whether or not any available acre will be placed into a BMP, the costs need to be evaluated. The total net costs accounting for the total design life capital, operating, and opportunity costs less the benefits provided by cost-share assistance and income from nutrient credits is calculated. For each BMP, the design life effects how long the farmer will incur operating and opportunity costs. The net present value[7] of the operating and opportunity costs are calculated assuming a five percent discount rate based on the USDA ERS Agricultural Services, Index for Prices Paid (USDA, 2011b) and consistent with the assumptions utilized by EPA in their cost estimations (CBPO, 2013a). Similarly, the net present value for potential nitrogen and phosphorus credits earned over the design life of the BMP is calculated. The total costs are then aggregated.

For example, continuous no till has an average installation cost of $339 per acre. There are no operating costs and the opportunity cost is negative (-$40 per year) based on the expected additional yield from this practice. The net present value of the opportunity cost is -$173.18 per acre with the five percent discount rate and a design life of five years. The total present value cost is $165.80 per acre. The benefits of this BMP are cost-share funds of $350 and annual credit sales of $5.46 in nitrogen credits and $1.97 in phosphorus credits per acre. The net present value of potential nutrient credit income is

7. Net present value takes into account that future payments (operating costs) or opportunity costs (lost revenue) are discounted due to factors such as inflation which reduces the purchasing power of a dollar with time.

$23.64 for nitrogen and $8.54 for phosphorus. The total benefits are $382.17 per acre. The net cost of this BMP is therefore $165.80 - $382.17 = -$216.27. Table 20 displays the average values of the total net costs for each of the BMPs.

Table 20. BMP Total Average Net Costs (Calculated)

BMP	Net Cost ($/acre)
Harvestable Cover Crop	$36.00
Small Grain Cover Crop	$38.00
Nutrient Management	$20.79
Early Planted Cover Crops	$23.28
15% Nitrogen Reduction on Corn	-$8.77
Continuous No-Till	-$216.37
Cropland to Forest	$935.56
Cropland to Hay	$246.76
Cropland to Mixed Open (fallow)	$282.12
Hay to Forest	$898.66
Hay to Mixed Open (fallow)	$245.22
Pasture to Forest	$1028.11

To estimate whether or not farmers are willing to participate in the nutrient market, the actual field-level costs (rather than average costs) must be considered. There are two approaches to determine the field-level costs to individual farmers in the Shenandoah SWCD: a structured model and a reduced form model. To estimate a structured model, the physical file data on BMPs could be used to correlate farm specific factors that lead to field-level costs. A structured form model using factors observed in the physical files would take the form represented in equation 1.

Equation 1. Field-level Cost Model

$FL_{costs} = f\,\{(AI_c \times FI_f), (AM_c \times FM_f), (AO_c \times FO_f)\}$

Where FL_{costs} are the field-level costs on a given farm. This is a function of the average installation costs (AI_c) adjusted by field-level installation factors (FI_f), the average operations and maintenance costs (AM_c) adjusted by the field-level operations and maintenance factors (FM_f), and the average opportunity costs (AO_c) adjusted by field-level opportunity cost factors (FO_f). AI_c, AM_c, and AO_c are the average values as cited in Table 20. FI_f, FM_f, and FO_f are functions that transform the average values and include factors such as soil type, farmer education level, and location, among other influences. The objective is to use the detailed physical files to determine the field-level specific factors that are used to derive field-level costs from average cost estimates. The detailed physical files provided some insight into the influence of different factors on field-level costs; however, there was not enough data to fully specify the model. The structured model was therefore deemed intractable.

With the inability to specify the structured form model, a reduced form model approach was taken. Rather than focusing on estimating the structure of the model form, this approach assumes there are unknown parameters in the model. The reduced form model uses the more robust aggregated cost database. Rather than attempting to estimate the influence of field-level factors on total field-level cost, the model assumes the heterogeneity in field-level costs based on observations and assumes a random assignment of costs across the Shenandoah SWCD.

To assign heterogeneity in field-level costs to individual fields (by acre) in the Shenandoah SWCD, a Monte Carlo simulation of the actual costs for any given acre was executed. To use a Monte Carlo, the data must have a normal distribution. Each of the BMPs' distributions was tested for skewness; where the skewness value is less than two, then it approximates a normal distribution (George & Mallery, 2010). All of the BMPs that are simulated have a skewness score of less than or equal to one, with the exception of the harvestable cover crop BMP having the greatest skewness at 1.74 which is still within the acceptable range to assume normal distribution.

The Monte Carlo algorithm used the mean, standard deviation, minimum, and maximum values found in the cost analysis (described in Chapter Three) for capital costs to determine the probability distribution for each of the BMPs. The distribution is normal and continuous within the probability range. The simulation was run 1,000 times for each result and 100 distinct results were produced. For example, the average capital cost of the early planted cover crop BMP is $53. The results of the Monte Carlo simulation are shown in figure 11 below. This graphic shows the frequency of costs estimated for each cost bin. As expected, there are more instances that the cost is close to the mean with 44 of the estimates from $40 to $60. The remainder of the estimates are distributed between the minimum observation from the sample of $6 to the maximum of $119.

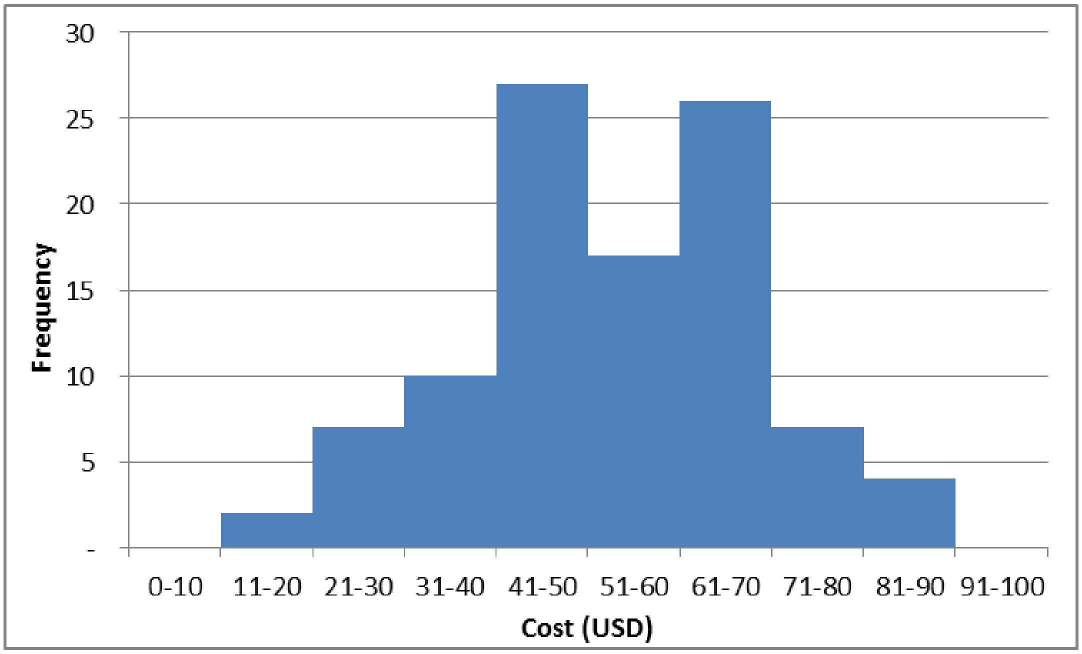

Figure 11. Simulation Results for Frequency of Early Planted Cover Crop BMP Capital Costs

The simulated capital costs are added to the operating and opportunity costs (single estimates based on literature averages) to derive the total net costs. These total net costs were used to assess whether or not farmers are willing to participate in the nutrient credit market.

The model is static whereby decisions from previous years do not influence a farmers' willingness to participate in the current year. The static nature of the model introduces the risk of autocorrelation in which there could be bias introduced by current decisions being correlated with previous decisions (time-series) and bias associated with spatial decisions. The model has the capability to compare different timeframes but does not incorporate dynamic algorithms based on the assumption that farmers will make decisions for their fields on an annual basis given current constraints (including the land they have available for BMPs or otherwise) but will not otherwise depend on the decisions made in the previous term. The BMPs have design lives that will take the land out of availability and it is in the interest of both the farmer and nutrient credit buyer to enter long term contracts to trade those credits for the entire period of the BMP design life (to reduce transaction costs). Therefore, the farmer's decision in time t+1 will be based on the land or options that don't already have a BMP implemented. Autocorrelation is minimized in the model by only allowing the farmer to make a decision based on current constraints.

Spatial autocorrelation is also inherent in the model; a farmer may have multiple fields and their willingness to generate credits on one field is likely a function of their overall willingness to participate in nutrient credit trading. With this in mind, the field decision is not really independent of the farm decision. Another risk with a reduced form model is heteroscedasticty. The observed actual BMP project costs from the aggregated cost database are being used to predict the behavior of all farmers in the Shenandoah SWCD. It is possible that subpopulations, such as those that have never installed a BMP or those that install BMPs but do not apply for cost-share assistance and therefore are outside of the observed population, will have cost structures that are dissimilar to those in the aggregated database. It is assumed that this is minimized since the factors that influence total costs across the SWCD are similar for all farmers including representative soil types, distance from riverfront, and acreage. There is a higher risk that heteroscedasticty will play a role if the analysis conducted for the Shenandoah SWCD is applied to the entire Virginia population of farmers.

Scenario Development

To be eligible for selling nutrient credits, a field must meet baseline conditions as previously described. Other economic analyses of nutrient trading in the Bay watershed have assumed that all fields would meet the baseline (e.g., Chesapeake Bay Commission, 2012) without evaluating costs. The current analysis included a comprehensive evaluation of baseline BMP costs. Rather than assuming all fields would meet the baseline, the results of the analysis of heterogeneity and of Base Case BMPs are used to determine two scenarios: a Low Scenario and a High Scenario.

There are two major constraints in the Low Scenario. The first is that only fields that have *already* met the baseline in the Base Case are eligible to install tradable BMPs. No additional fields will meet the baseline in this scenario. The second constraint is that tradable BMPs must have a negative total net cost. This represents a conservative and realistic scenario.

A High Scenario is also developed. For this scenario, rather than constraining tradable BMPs to fields that have already met the baseline in the Base Case, additional baseline BMPs are allowed for installation. It is assumed that all eligible fields will install BMPs to meet the baseline for this optimistic scenario. Installation of tradable BMPs is still constrained to those that have a negative total net cost.

For both scenarios, price and demand are exogenous to the model. A number of price scenarios are run to estimate the influence of price on potential magnitude of credits provided by agricultural BMPs. Table 21 displays the six alternative scenarios. The first is based on the current (2014) fixed prices for nitrogen and phosphorus credits determined by the Virginia Credit Trading Exchange; \$3.05 for nitrogen and \$4.93 for phosphorus (Virginia Nutrient Credit Exchange Association, 2013). This price is modeled using constraints of both the low and the high scenario.

Table 21. Price Scenarios in Current Analysis

	Low Scenario	High Scenario
Fixed Price	Alternative One	Alternative Two
Wastewater Treatment Facility Based Price	Alternative Three	Alternative Four
Stormwater Management BMP Based Price	Alternative Five	Alternative Six

Alternatives three and four assume that once prices are allowed to float (~2018) the low end of the estimated wastewater treatment plant costs to reduce a pound of nitrogen and phosphorus are indicative of market prices. In Virginia, estimated wastewater treatment plant retrofit costs to reduce a pound of nitrogen range from $15.80 to $47.90 per pound (Senate Finance Committee, 2011). To be conservative, this alternative assumes $15.80 for a nitrogen credit. The cost to a wastewater treatment plant of reducing a pound of phosphorus is estimated at $310 (Maryland Clean Agriculture Coalition, 2014). The wastewater treatment facility cost based price is modeled using both the low and high scenario assumptions.

Urban stormwater costs to reduce nitrogen are even higher than wastewater treatment facility estimated costs. Under current Virginia trading rules, urban stormwater cannot be mitigated by purchasing agricultural BMP credits (VDEQ, 2008). To understand the influence that allowing trade between urban and agriculture, a third price based on urban stormwater costs was modeled. According to the Chesapeake Bay

Commission (2012), stormwater costs to reduce nitrogen range from over $300 to nearly $1,000 per pound of nitrogen reduced depending on the BMP. A recent study based in the James River Basin in Virginia estimated the urban stormwater costs to reduce a pound of nitrogen and phosphorus (The Center for Watershed Protection, 2013). The lowest costing urban stormwater management BMP values were adopted as a stormwater based price; nitrogen is $151 per pound and phosphorus is $1,384 per pound in this alternative. This price is modeled with the constraints in the low and high scenario.

Demand is exogenous to the model for all alternatives. With wastewater treatment likely to be the largest driver of demand under current rules, the credits needed by these facilities indicate demand will be considerable. Wastewater treatment facilities in the Potomac watershed are required to reduce their annual load by 111,000 pounds of nitrogen and 169,000 pounds of phosphorus by 2025 (ChesapeakeStat, 2014). With the 2:1 ratio in place for point sources to purchase offsets from non-point sources, this is equivalent to 222,000 nitrogen credits and 338,000 phosphorus credits needed. This does not account for growth in either capacity or new facilities. The total offsets required by wastewater treatment facilities and regulated stormwater including growth have been estimated at 716 billion pounds of nitrogen and 112 billion pounds of phosphorus by 2025[8] (Chesapeake Bay Commission, 2012).

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8. This estimate accounts for growth in capacity and new wastewater treatment facilities based on population growth estimates for the region.

Results

The baseline BMPs cannot generate any income from selling nitrogen or phosphorus credits. The results of the analysis of field-level costs in the Shenandoah SWCD finds that even with cost-share payments, except for those which receive 100 percent funding (livestock exclusion), costs exceed benefits. Heterogeneity does influence how much the total net costs are for the baseline BMPs. For instance, harvestable cover crops may be $11 per acre for one field and $40 per acre for another field; there is considerable variance. For the alternative price scenarios, baseline BMPs are either constrained to currently implemented BMPs (low scenario) or are allowed to increase to the maximum extent (high scenario). The results of the alternative price scenarios are described below.

Fixed Price Alternatives

Alternatives one and two use the fixed price for nitrogen and phosphorus. Based on the Monte Carlo simulation of the total net costs for the BMPs, early planted cover crops have a negative cost ten percent of the time. The 15 percent nitrogen reduction on corn BMP is cost negative 100 percent of the time. Continuous no-till has a negative net cost nearly all the time (94%). None of the land conversion BMPs had benefits that exceed costs. Heterogeneity in field-level BMPs did influence how often an early planted cover crop and continuous no-till BMPs are to be expected; however, it did not influence any of the other BMPs under given conditions.

Net costs of early planted cover crops ranged from a negative cost (profit) of $13 to a net cost of $57 per acre. The 15 percent nitrogen reduction on corn BMP yields a profit of $9 per acre. Continuous no-till has a net cost as high as $79; however, this BMP generally yields a profit with results as high as $325 per acre (these are largely cost savings rather than income).

In the Low Scenario, only fields that are already meeting the baseline are eligible to receive credits for tradable BMPs. Table 22 shows the acres in each BMP by land use classification for one year as a result of the Low Scenario analysis.

Table 22. Fixed Price, Low Scenario: Additional Acres in BMPs

BMP	Hay	Cropland (Corn)	Cropland (Other)	Pasture
Early Planted Cover Crops	291	109	166	0
15% Nitrogen Reduction on Corn	0	1,090	0	0
Continuous No-Till	2,738	1,024	1,562	0

Utilizing the effectiveness rates for each of the BMPs by land use classification, the annual pounds of nitrogen and phosphorus reduced results are displayed in Table 23.

Table 23. Fixed Price, Low Scenario: Pounds of Nitrogen and Phosphorus Reduced

BMP	Nitrogen Reduced (lbs)	Phosphorus Reduced (lbs)
Early Planted Cover Crops	595	0
15% Nitrogen Reduction on Corn	2,833	0
Continuous No-Till	9,532	2,130
Total	**12,960**	**2,130**

In the High Scenario, it was assumed that all fields would meet the baseline and be eligible for receiving credits for the installation of tradable BMPs. The results of this scenario include both the additional lands in baseline BMPs as well as the land in tradable BMPs. Table 24 shows the acres in each BMP by land use classification for one year as a result of the High Scenario analysis.

Table 24. Fixed Price, High Scenario: Additional Acres in BMPs

BMP	Hay	Cropland (Corn)	Cropland (Other)	Pasture
Harvestable Cover Crop	34,676	12,972	19,785	0
Small Grain Cover Crop	17,864	6,683	10,192	0
Nutrient Management	53,669	20,077	30,622	0
Early Planted Cover Crops	5,658	2,117	3,228	0
15% Nitrogen Reduction on Corn	0	21,167	0	0
Continuous No-Till	53,187	19,897	30,347	0

Utilizing the effectiveness rates for each of the BMPs by land use classification, the annual pounds of nitrogen and phosphorus reduced results are displayed in Table 25.

Table 25. Fixed Price, High Scenario: Pounds of Nitrogen and Phosphorus Reduced

BMP	Nitrogen Reduced (lbs)	Phosphorus Reduced (lbs)
Harvestable Cover Crop	168,585	0
Small Grain Cover Crop	211,906	0
Nutrient Management	0	0
Early Planted Cover Crops	11,553	0
15% Nitrogen Reduction on Corn	55,034	0
Continuous No-Till	185,141	41,372
Total	**632,220**	**41,372**

Overall, the potential reductions of nitrogen and phosphorus are far less than required to offset future wastewater treatment facility wasteloads. While heterogeneity plays a small role at current fixed credit prices, the total costs of BMPs overwhelmingly exceed potential benefits to farmers and influence the potential nutrient reductions that can be attained via trading. The current fixed price for nitrogen and phosphorus credits do not reflect the likely market price of a credit. The fixed prices should reflect the estimated costs of wastewater treatment plant costs to reduce nitrogen and phosphorus. The results of the alternative price analysis assuming credits will be the minimum cost that wastewater treatment facilities incur to reduce nutrients are described next.

Wastewater Treatment Facility Based Alternatives

Alternatives three and four assume that the price of credits is allowed to float. The estimated price for a nitrogen or phosphorus credit is based on the lowest cost estimate for a wastewater treatment facility with nitrogen at $15.80 and phosphorus at $310. Based on the Monte Carlo simulation of the total net costs for the BMPs, early planted cover crops have a negative cost 23 percent of the time. The 15 percent nitrogen reduction on corn BMP is cost negative 100 percent of the time. Continuous no-till has a negative cost nearly 100 percent of the time. None of the land conversion BMPs had benefits that exceed costs. Heterogeneity in field-level BMPs did influence how often an early planted cover crop is to be expected; however, it did not influence any of the other BMPs under given conditions.

Net costs of early planted cover crops ranged from a negative cost (profit) of $26 to a net cost of $44 per acre. The 15 percent nitrogen reduction on corn BMP yields a profit of $40 per acre. Continuous no-till yields a profit from $548 to $953. Table 26 shows the acres in each BMP by land use classification for one year as a result of the Low Scenario analysis for the wastewater treatment based price.

Table 26. Wastewater Treatment Based Price, Low Scenario: Additional Acres in BMPs

BMP	Hay	Cropland (Corn)	Cropland (Other)	Pasture
Early Planted Cover Crops	670	251	382	0
15% Nitrogen Reduction on Corn	0	1,090	0	0
Continuous No-Till	2,913	1,090	1,662	0

Utilizing the effectiveness rates for each of the BMPs by land use classification, the annual pounds of nitrogen and phosphorus reduced results are displayed in Table 27.

Table 27. Wastewater Treatment Based Price, Low Scenario: Pounds of Nitrogen and Phosphorus Reduced

BMP	Nitrogen Reduced (lbs)	Phosphorus Reduced (lbs)
Early Planted Cover Crops	5,918	1,165
15% Nitrogen Reduction on Corn	5,047	436
Continuous No-Till	3,377	665
Total	**14,342**	**2,266**

The results of the High Scenario include both the additional lands in baseline BMPs as well as the land in tradeable BMPs. Table 28 shows the acres in each BMP by land use classification for one year as a result of the High Scenario analysis with wastewater treatment based credit prices.

Table 28. Wastewater Treatment Based Price, High Scenario: Additional Acres in BMPs

BMP	Hay	Cropland (Corn)	Cropland (Other)	Pasture
Harvestable Cover Crop	34,676	12,972	19,785	0
Small Grain Cover Crop	17,864	6,683	10,192	0
Nutrient Management	53,669	20,077	30,622	0
Early Planted Cover Crops	13,014	4,868	7,425	0
15% Nitrogen Reduction on Corn	0	21,167	0	0
Continuous No-Till	56,582	21,167	32,284	0

Utilizing the effectiveness rates for each of the BMPs by land use classification, the annual pounds of nitrogen and phosphorus reduced results are displayed in Table 29.

Table 29. Wastewater Treatment Based Price, High Scenario: Pounds of Nitrogen and Phosphorus Reduced

BMP	Nitrogen Reduced (lbs)	Phosphorus Reduced (lbs)
Harvestable Cover Crop	168,585	0
Small Grain Cover Crop	211,906	0
Nutrient Management	0	0
Early Planted Cover Crops	26,573	0
15% Nitrogen Reduction on Corn	55,034	0
Continuous No-Till	196,959	44,013
Total	**659,057**	**44,013**

The results of the alternative scenario using wastewater treatment facility costs as an indicator of the expected credit prices yields only a small change in the reduction of nitrogen and phosphorus. This alternative increases credits of nitrogen supplied by agriculture by four percent over the fixed price case. Phosphorus credits are increased by six percent over the fixed price case. The results of the alternative price analysis assuming credits will be the minimum that urban stormwater management BMPs cost to reduce nutrients is described next.

Stormwater Management BMP Based Alternatives

Alternatives five and six assume that the price of credits is allowed to float. The estimated price for a nitrogen or phosphorus credit is based on the lowest cost estimate for a stormwater management BMP with nitrogen at $151 and phosphorus at $1,384. Based on the Monte Carlo simulation of the total net costs for the BMPs, early planted cover crops, 15 percent nitrogen reduction on corn and continuous no-till have a negative net cost 100 percent of the time. None of the land conversion BMPs had benefits that exceed costs. Heterogeneity in field-level BMPs do not influence whether or not benefits exceed costs for any of the BMPs; however, for early planted cover crops the potential profit does vary.

Profits from early planted cover crops range from $91 to $161 per acre. The 15 percent nitrogen reduction on corn BMP yields a profit of $375 per acre. The continuous no-till BMP yields a profit ranging from $3,456 to $3,860 per acre. Table 30 shows the acres in each BMP by land use classification for one year as a result of the Low Scenario analysis.

Table 30. Stormwater Management Based Price, Low Scenario: Additional Acres in BMPs

BMP	Hay	Cropland (Corn)	Cropland (Other)	Pasture
Early Planted Cover Crops	2,913	1,090	1,662	0
15% Nitrogen Reduction on Corn	0	1,090	0	0
Continuous No-Till	2,913	1,090	1,662	0

Utilizing the effectiveness rates for each of the BMPs by land use classification, the annual pounds of nitrogen and phosphorus reduced results are displayed in Table 31.

Table 31. Stormwater Management Based Price, Low Scenario: Pounds of Nitrogen and Phosphorus Reduced

BMP	Nitrogen Reduced (lbs)	Phosphorus Reduced (lbs)
Early Planted Cover Crops	5,948	0
15% Nitrogen Reduction on Corn	2,833	0
Continuous No-Till	10,140	2,266
Total	**18,922**	**2,266**

The results of the High Scenario include both the additional lands in baseline BMPs as well as the land in tradeable BMPs. Table 32 shows the acres in each BMP by land use classification for one year as a result of the High Scenario analysis assuming a price reflecting stormwater management BMP costs.

Table 32. Stormwater Management Based Price, High Scenario: Additional Acres in BMPs

BMP	Hay	Cropland (Corn)	Cropland (Other)	Pasture
Harvestable Cover Crop	34,676	12,972	19,785	0
Small Grain Cover Crop	17,864	6,683	10,192	0
Nutrient Management	53,669	20,077	30,622	0
Early Planted Cover Crops	56,582	21,167	32,284	0
15% Nitrogen Reduction on Corn	0	21,167	0	0
Continuous No-Till	56,582	21,167	32,284	0

Utilizing the effectiveness rates for each of the BMPs by land use classification, the annual pounds of nitrogen and phosphorus reduced results are displayed in Table 33.

Table 33. Stormwater Management Based Price, High Scenario: Pounds of Nitrogen and Phosphorus Reduced

BMP	Nitrogen Reduced (lbs)	Phosphorus Reduced (lbs)
Harvestable Cover Crop	168,585	0
Small Grain Cover Crop	211,906	0
Nutrient Management	0	0
Early Planted Cover Crops	115,534	0
15% Nitrogen Reduction on Corn	55,034	0
Continuous No-Till	196,959	44,013
Total	**748,018**	**44,013**

If urban stormwater was allowed to be mitigated by purchasing nutrient credits and prices reflected the low end of stormwater management BMPs, the increase in nutrient credits by agriculture would increase considerably over the current fixed price scenario. Nitrogen credits would increase by 15 percent and phosphorus credits would increase by 6 percent over alternatives one and two. The stormwater based price alternative increase in nutrient credits supplied by agriculture is largely reflective of the increased viability (benefits outweighing costs) for early planted cover crops.

Summary

The three price scenarios combined with the low and high cases yield results for six total scenarios. Table 34 summarizes the pounds of nitrogen and phosphorus potentially reduced for each of the scenarios. While higher credit prices increase the quantity of nitrogen reduced, there is a much more significant increase in nitrogen reduced in the high versus the low case. Given current cost-share rates, the analysis of baseline BMP costs found that farmers incur net costs for the installation and maintenance of these practices. The results of this analysis indicate that the high case is unlikely to be attained and that the required baseline is a substantial barrier to trading.

Table 34. Summary of Nitrogen and Phosphorus Reduced as a Result of Price Scenarios

	Nitrogen (lbs)		Phosphorus (lbs)	
	Low	High	Low	High
Fixed Price	12,960	632,220	2,130	41,372
Wastewater Treatment Facility Based Price	14,342	659,057	2,266	44,013
Stormwater Management BMP Based Price	18,922	748,018	2,266	44,013

The price for a nutrient credit is determined exogenously to the model. Two scenarios are based on the current fixed price and four scenarios are associated with prices that buyers might be willing to pay based on their costs. It is also possible to calculate the breakeven price for the BMPs. The breakeven price represents the price at which the net costs (total net present value of installation, operating, and opportunity costs) is equivalent to the total benefits (net present value of cost-share and income from nutrient credits). The breakeven is calculated for a nitrogen credit. To derive the breakeven price, it is assumed that all else remains constant including the price of a phosphorus credit. Table 35 shows the breakeven price for each of the BMPs. The variance in the breakeven price represents the heterogeneity in the costs associated with the BMPs, the potential for cost-share, as well as the effectiveness of each of the BMPs at reducing nitrogen. For example, the land conversion of pasture to forest has the highest breakeven price and also the lowest effectiveness at 0.91 pounds of nitrogen per acre of BMP. In contrast, cropland to forest conversion has a relatively high effectiveness at 10.91 pounds per acre and also has high opportunity costs of productive land.

Table 35. Tradeable BMP Nitrogen Credit Breakeven Prices

BMP	Breakeven Price
Early Planted Cover Crops	$26.32
15% Nitrogen Reduction on Corn	$3.05
Continuous No-Till	$3.05
Cropland to Forest	$11.31
Cropland to Hay	$7.17
Cropland to Mixed Open (fallow)	$6.31
Hay to Forest	$22.16
Hay to Mixed Open (fallow)	$15.22
Pasture to Forest	$111.50

Discussion

Building on an analysis of the heterogeneity in field-level costs, an assessment of the magnitude of nitrogen and phosphorus nutrient credits supplied by the Shenandoah SWCD was completed. Under current price conditions, a Low Scenario – a conservative, realistic case – revealed an expected 12,960 pounds of nitrogen reduction and 2,130 pounds of phosphorus reduction for one year. The High Scenario – a more optimistic case – suggests as much as 632,220 pounds of nitrogen may be reduced and 41,372 pounds of phosphorus may be reduced in a given year.

The total contribution from the agricultural sector in the Shenandoah SWCD is 2,810,442 pounds of nitrogen and 1,137,036 pounds of phosphorus on an annual basis. The potential reduction in the Fixed Price, Low Scenario represents 0.5 percent of the current nitrogen load and 0.2 percent of the current phosphorus load. Even the Fixed Price, High Case only represents 27 percent of the nitrogen load and four percent of the phosphorus load.

In the current Virginia nutrient exchange market, there have been a number of trades between point sources. In 2013, there were 88,922 nitrogen credits and 13,088 phosphorus trades completed in the Potomac River watershed (VDEQ, 2013). All of the trades were between wastewater treatment facilities that exceeded their load allocation and facilities that maintained excess allocation. If these credits were purchased from non-point sources rather than point sources there would be a 2:1 credit ratio. This indicates current demand is 177,844 pounds of nitrogen and 26,176 pounds of phosphorus in the Potomac River watershed.

There is currently demand in the Potomac River watershed that is being met by point sources rather than agricultural non-point sources. This indicates that either the costs of reducing nitrogen and phosphorus are less than estimated for wastewater facilities or, at current prices, there is not a sufficient incentive to drive the supply of nutrient credits from agriculture. This analysis finds that with the current fixed prices, in the Low Scenario, the Shenandoah SWCD would supply less credits than could meet demand in the basin. The High Scenario does provide more than enough credits for current demand today. However, as credit demand increases through 2025 as a result of the TMDL compliance schedule and population growth requiring capacity increases in wastewater treatment, the credits needed greatly exceed the quantity provided in either of the scenarios. Population in the Chesapeake Bay region is expected to increase by 29 percent or 4.6 million persons by 2030 (Chesapeake Bay Program Population estimates).

A significant finding of the analysis is not that heterogeneity in field-level costs affects the willingness of farmers to provide nutrient credits so much as the costs of BMPs are higher than estimated in most other analyses of nutrient trading in the Chesapeake Bay. The high cost of BMPs with current prices fixed at low values has led to the nonexistent point-non-point source nutrient market in Virginia. In addition, in Virginia, the high cost of meeting the baseline greatly reduces the potential nutrient credit supply. This analysis finds that baseline BMPs cannot be implemented with cost-share funding alone. Stephenson et al. (2010) also noted that Virginia "law dictates the development of fairly stringent non-point source baseline requirements that significantly reduces per acre nutrient reductions that can be produced."

The current fixed price of nutrient credits is expected to be allowed to float starting in 2018. To assess the effects of future credit prices, additional price scenarios were analyzed. Using wastewater treatment costs to reduce nutrients as a proxy for the future market price, a four percent increase in nitrogen credits and six percent increase in phosphorus credits is expected from agriculture in the Shenandoah SWCD. If the market regulations in Virginia were extended to allow urban areas to purchase credits to mitigate stormwater nutrient pollution, credit prices might be substantially higher. Under this price scenario, the Shenandoah SWCD would contribute 15 percent more nitrogen credits and six percent more phosphorus credits. Evaluating the sensitivity of the willingness to provide nutrient credits based on various potential prices illustrates that the credit price will have to be much higher than current fixed prices to incentivize agricultural BMP installation.

This research has a number of implications for policy, economic analysis, and environmental market design. To encourage trading and realize its efficiency benefits, there are a number of policy options. Most significantly, allowing the price to float may have a considerable impact on the number of trades as indicated by the alternative price scenarios. Additionally, changing the rules on baseline and BMPs that are eligible for trading could significantly influence the number of agricultural nutrient credits supplied. The difference between the low and high scenarios under all price assumptions illustrate that the BMP baseline is a barrier to significant market participation.

Finally, from an economic analysis perspective, this study highlights a gap in the research. There are many examples of nutrient market studies that use watershed wide average BMP costs (e.g., Faeth, 2000; Ribaudo, Heimlich, and M. Peters, 2005; Hanson and McConnell, 2008; Chesapeake Bay Commission, 2012). There have also been studies which evaluate nutrient markets from a farm level perspective, modeling a single farm using detailed data (e.g., Movafaghi et al., 2013). The current analysis scales up the farm level analysis to an entire SWCD (and could be further scaled up to include multiple SWCDs or to the state). Unlike previous watershed analyses, average BMP costs are not used and heterogeneity of costs is preserved in the model. This analysis illustrates the additional information provided by preserving heterogeneity and collecting more detailed cost data. For economic analyses, such as those on the potential benefits of nutrient trading for the Chesapeake Bay, using more intricate data can improve decision-making in the Bay. Chapter five will further explore the broader implications of the current research in nutrient trading policy in the Chesapeake Bay watershed.

CHAPTER FIVE: CONCLUSIONS

According to the latest EPA data, sixty-seven percent of the United States' waterways (including rivers, streams, lakes, reservoirs, ponds, bays, and estuaries) are impaired (EPA, 2015). In rivers and streams, nutrients are the third most common cause for poor water quality (EPA, 2015). Current nutrient pollution is contributed by point- and non-point sources including, importantly, agriculture. Across the Nation, agriculture is the largest source of pollution to rivers and streams according to the EPA (2015). The benefits of reducing nutrient export from farms largely accrue to society rather than to the farmer. Without compensation, farmers may be lacking the incentive to change their practices to better manage nutrients, creating an externality.

To improve water quality by reducing nutrients from agricultural sources is a technical, policy, and economic challenge. From the technical standpoint, BMPs are designed to reduce nutrient export from farms by introducing less nutrients and retaining those nutrients that are introduced on the field. The Clean Water Act (33 U.S.C. §1251 et seq. (1972)) is the regulatory authority by which the EPA can set limits on the quantities of pollutants discharged into the U.S.'s surface waters, including nutrient pollution.

Based on the Act, the EPA established the Chesapeake Bay Total Maximum Daily Load in 2010 (EPA, 2011). The TMDL establishes a limit on nutrient pollution loads to the Bay and its tidal rivers. Nutrient TMDLs are policies designed to reduce nutrient loads to improve water quality; however, agriculture is largely unconstrained under the Clean Water Act. Rather than command and control, alternative voluntary policy instruments are being employed to encourage BMPs on agricultural lands to address nutrient pollution. Alternative policy approaches seek to address the economics by utilizing incentives in the form of subsidies (i.e., cost-share) or nutrient credit markets. However, across the United States, water quality markets have had limited success in terms of market activity (Newburn and Woodward, 2012).

In Virginia, multiple policy instruments are being employed to reduce nutrient pollution to comply with the Chesapeake Bay TMDL. The State provides an interesting case study. Lessons can be learned on the performance of nutrient reductions approaches. These lessons may be applicable to other states in the watershed and in other watersheds throughout the United States.

Wastewater treatment facilities, urban stormwater, and confined animal feedlots are subject to compensatory allocation caps for nitrogen and phosphorus (VDEQ, 2011 [9 VAC 25 – 820]). Subsidy programs are being deployed in the form of cost-sharing of agricultural BMPs by both the State and the USDA (DCR, 2014a; USDA, 2014). Finally, the VADEQ designed a cap and trade market-based approach that allows wastewater treatment facilities to purchase nutrient credits to offset quantities above their compensatory cap from other facilities or the installation of agricultural BMPs (VDEQ, 2008).

Previous economic analyses of the Chesapeake Bay watershed have indicated the potential for a robust Bay-wide point- and non-point source nutrient credit market (CBC, 2012; Wainger et al, 2013; USDA, 2013 forthcoming). While enabling regulation has been in place since 2009 in Virginia, wastewater treatment facilities have yet to purchase any credits from agricultural BMPs (VDEQ, 2013). One likely reason for the lack of actual trading in contrast to expected trading is due to a faulty assumption or incomplete information in previous analyses. To better inform policy decisions there are a number of agricultural factors that need to be understood, including: improved information on the costs of agricultural BMPs, the influence of trading policies, and the external factors that influence farmer participation in nutrient credit markets.

A central thesis that was tested in this dissertation is that the heterogeneity in field-level costs of agricultural BMPs influences farmers' willingness to participate in nutrient markets. This research provided more detailed information on costs of BMPs and evaluated the influence of the fixed cost and baseline requirements on Virginia's trading policy. Key findings include:

1. There is significant heterogeneity in field-level costs, with coefficients of variation ranging from 19 to 72 percent.
2. Under current fixed nutrient credit prices, farmers are expected to supply only 0.5 percent of the current nitrogen load and 0.2 percent of the current phosphorus load in nutrient credits.
3. Baseline BMP installation costs are a significant hurdle to substantial market activity.

Discussion of Policy Relevance

The high degree of heterogeneity in costs of implementation of BMPs for farmers in the Shenandoah SWCD contributes to a lack of trading in nutrient markets. In comparison to previous economic analyses based on average costs (CBC, 2012; Wainger et al, 2013; USDA, 2013 forthcoming), it was found that field-level costs exceed estimated values at least fifty percent of the time, the standard deviation about the mean is significant, and the coefficients of variation are substantial. (See Chapter Three for detailed cost discussion.) This indicates that many projects would not be economic under analytical assumptions of previous analyses.

This finding has direct relevance to water quality management in the Chesapeake Bay. Virginia's Watershed Implementation Plan (WIP) relies on nutrient trading to equitably implement the "challenging pollution reduction requirements imposed by the Bay TMDL" (Commonwealth of Virginia, 2010). Depending on previous analyses of the potential for trading is misleading. Those analyses use average costs which underestimate the cost of BMP implementation for many farmers. They also assume that all farmers will meet the baseline. This leads to an overestimation of farmer provision of nutrient credits. Previous analyses don't identify the challenge of meeting the baseline or consider the effects of the fixed price. Without considering this information, the likelihood that Virginia can achieve environmental objectives most efficiently is reduced.

Findings in this research suggest the need for a revision in the design of the Virginia nutrient credit market. An analysis of potential nutrient credits supplied by agriculture in the Shenandoah SWCD identified the baseline BMP requirement as a hurdle to widespread market participation. Under current Virginia trading regulations baseline BMPs are not eligible for credit. With this constraint, potential nitrogen reductions from agriculture ranged from 12,960 to 18,922 pounds under various credit price scenarios. If there were no baseline requirement, as much as 632,220 to 748,018 pounds of nitrogen could be reduced – a 40 to 50 fold increase.[9] Similarly, phosphorus reductions without a baseline requirement could be 20 times as high (analytical methodology and detailed results described in Chapter Four).

A baseline requirement for agricultural non-point sources is based in economic theory. There are both benefits and costs associated with this requirement. The purpose of a baseline requirement is to incentivize and reward good behavior; by requiring a minimum level of stewardship prior to entering the market, those farmers that have already adopted BMPs are rewarded (Ghosh et al, 2011). Those farmers that have not installed the required baseline BMPs are at a competitive disadvantage compared to the early adopters because they will have to make this additional investment to participate in the market (ibid). Ultimately, Ghosh et al (2011) found that the baseline requirement influences the cost of providing non-point source offsets which thereby affects the supply.

The current conditions in the Shenandoah SWCD are such that baseline requirements are being met by early adopters at a rate of only 5 percent (nutrient management) to 7 percent (harvestable and small grain cover crops). Based on these low levels of adoption of baseline BMPs and the evidence that the costs associated with

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9. This scenario assumes farmers whom hadn’t met the baseline in 2014 would meet the baseline. The quantity of nitrogen reduced includes gains from additional baseline BMP implementation.

installing these BMPs is a hurdle to market activity, one policy recommendation is to allow baseline BMPs to earn credits[10]. Without removing cost-share assistance, allowing additional income via selling credits has the potential to greatly increase participation in the market. This would also address the primary goal to increase the contribution of nutrient reductions from agriculture. To fully consider this policy recommendation three scenarios were assessed. The results of the analysis are described below.

Virginia Trading Regulations Alternative Analysis

An analysis was designed to assess the impact of revising Virginia nutrient credit trading regulations to allow farmers to sell credits for the installation of baseline BMPs (cover crops (regular timing), nutrient management, and riparian buffers). The analysis includes three scenarios with the credit price assumptions described in Chapter Four: fixed price, wastewater facility-based price, and stormwater management BMP based price. The results are displayed in Table 36 and figures below. The table includes the percentage of the 2025 required nutrient reductions by wastewater treatment plant facilities in the Shenandoah SWCD.

Table 36. Nitrogen and Phosphorus Reduced under Revised Baseline BMP Policy

	Nitrogen (lbs)	Target %	Phosphorus (lbs)	Target %
Fixed Price	27,897	4%	3,813	3%
Wastewater Treatment Facility Based Price	286,095	40%	32,615	29%
Stormwater Management BMP Based Price	467,477	65%	43,135	38%

10. The low level of adoption of baseline BMPs in the Shenandoah SWCD limits the risk of discouraging early adopters of voluntary BMPs. The author suggests that the costs of implementation are a sufficient hurdle to market activity that outweighs the benefit of encouraging good stewardship.

Revising the trading regulations to allow farmers to claim baseline BMPs for nutrient credits (and sell those credits) greatly increases the expected participation in the market. Figures 12 and 13 compare the nitrogen and phosphorus reductions achieved as a result of trading under the current and recommended policy for baseline BMPs. For the fixed price scenario, there is a 115 percent increase in nitrogen and 79 percent increase in phosphorus reduction. For the wastewater treatment and stormwater treatment based price scenarios, nitrogen reductions are increased by 1,895 percent and 2,371 percent respectively. Phosphorus reductions are increased by 1,339 percent and 1,804 percent for the wastewater and stormwater based scenarios.

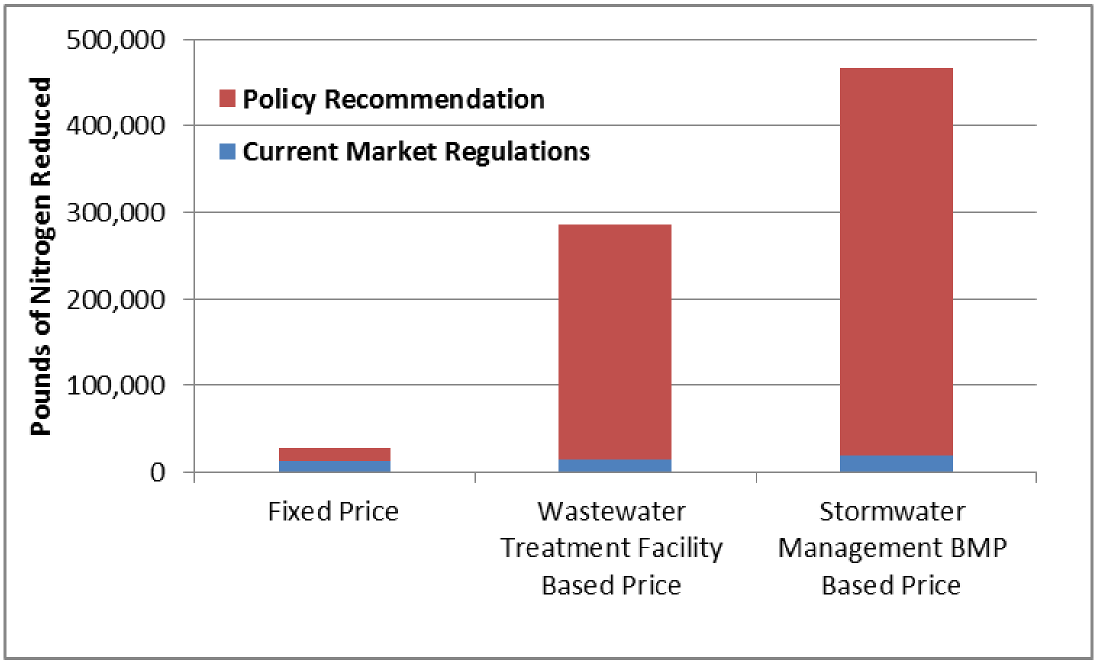

Figure 12. Comparison of Nitrogen Reductions under Current and Recommended Baseline BMP Policy

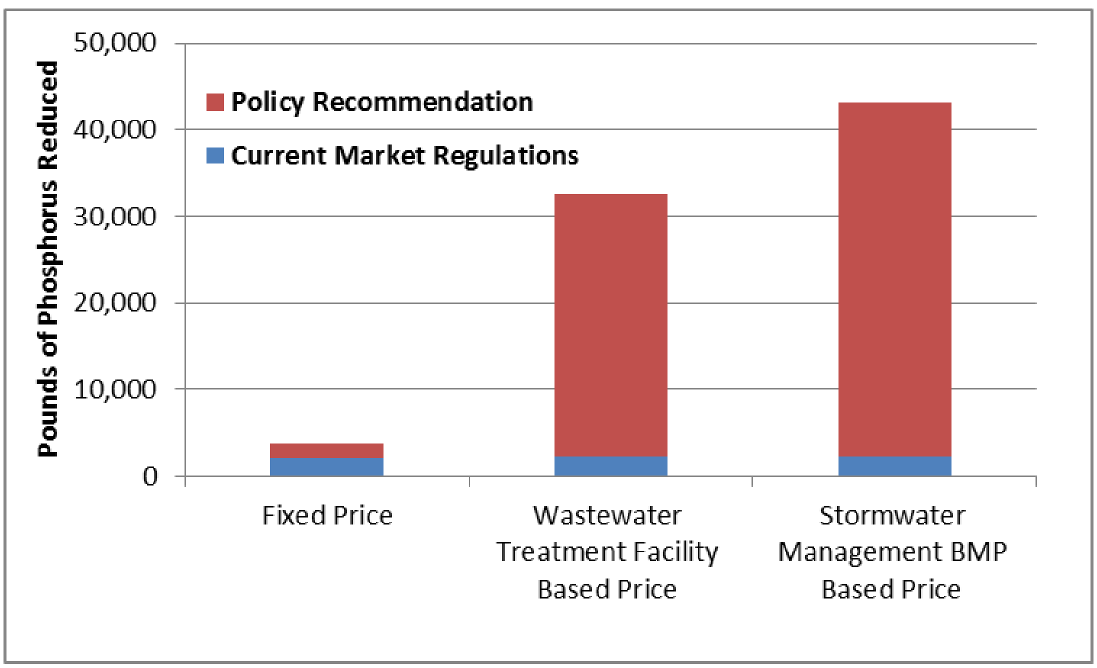

Figure 13. Comparison of Phosphorus Reductions under Current and Recommended Baseline BMP Policy

As the graphs illustrate, revising the policy to allow for the sale of credits for baseline BMPs has a significant impact on the amount of participation in the nutrient credit exchange. The revenue that can be earned from the sale of a nutrient credit decreases farmers' actual costs to implement baseline BMPs, significantly increasing the incentive to conduct these practices. This can lead to a more cost-efficient implementation of the Chesapeake Bay TMDL. In addition to the implications of this finding for trading, the results of the analysis of costs of BMPs at the field-level indicate that baseline BMPs will generally not be implemented without additional incentives. While many of these practices are targeted with cost-share funds, given current implementation rates of two to five percent for cover crops and five percent for nutrient management planning,[11] it is not likely that the BMPs will be installed to the extent assumed in the WIP.

Contribution to the Field

This research contributes to the nexus between agricultural economics and environmental policy. The analysis adds to the literature on the potential for cap and trade policy to control non-point source nutrient pollution. In the United States, examples other than the effort in the Chesapeake Bay watershed include the Greater Miami River Watershed, Southwest Ohio Trading Program, the Ohio River Basin Trading Project, an interstate agreement in the pilot phase, and the Tar-Pamlico Watershed in North Carolina (Miami Conservancy, 2014; EPRI, 2012; Green, 1997). Beyond the United States, water

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11. These values are for the Shenandoah SWCD based on state reported land in BMPs and the Agricultural Census of total lands available.

quality trading programs have been implemented in Australia, Canada, and New Zealand and are being assessed for development in Finland, Sweden, and other countries (Shortle, 2012). Specifically, the analysis provides new insight on the potential for wastewater treatment plant and agricultural BMP nutrient credit trading based on field-level costs. While there are many examples of nutrient market studies that use watershed wide average BMP costs (e.g., Faeth, 2000; Ribaudo, Heimlich, and M. Peters, 2005; Hanson and McConnell, 2008; Chesapeake Bay Commission, 2012) and single farm level nutrient studies (e.g., Movafaghi et al., 2013), no previous regional, field-level analysis has been discovered here. The results here identified the relatively high costs of agricultural BMPs and heterogeneity in the installation costs of agricultural BMPs in the Shenandoah SWCD, and also indicate that farmers' willingness to participate in nutrient credit markets is likely considerably less than previously estimated due to low incentives.

The research also contributes to the field of policy analysis and more specifically pollution trading by identifying key features of market design that hinder a robust market. The fixed price in the current Virginia trading regulations was found to be significantly lower than needed to incentivize BMP installation by farmers. Estimated costs of wastewater facility and urban stormwater management BMPs to reduce nutrients are sufficiently higher than pegged prices. The price should be allowed to float to encourage an efficient allocation of nutrient reduction among the various polluters.

The high costs of the baseline BMPs required in Virginia's trading regulations are also major hurdle to trading. An alternative scenario analysis which allowed baseline BMP installation to receive both cost-share and tradeable credits indicated that revising this regulation would not only lead to more participation in the market, but greater reductions of nutrient pollution from agriculture overall.

Finally, this dissertation identifies the need for, and benefits of, conducting more detailed analyses at a larger scale. By incorporating the inherent heterogeneity in field-level costs into the assessment of nutrient trading potential in the Chesapeake Bay watershed, a much more conservative estimate of farmer participation was revealed. The scale of this analysis illustrates the policy benefits of additional information provided by preserving heterogeneity and collecting more detailed cost data. This is a useful lesson for policy and economic analyses that often use average values at regional, state, and national scales. While considering every farm may be technically infeasible or cost-prohibitive, including more discrete data than broad watershed averages greatly influences the outcome of the analysis. In the context of decision-making, this hybrid scale approach may provide a great improvement towards realizing the potential for environmental markets.

Research Questions Still Outstanding

This study focused on heterogeneity of costs of agricultural BMPs in the Shenandoah SWCD and how that influenced farmers' willingness to participate in nutrient credit markets. The variance in the capital costs of BMPs were explicitly evaluated and modeled in this dissertation research. There are additional cost and benefit factors that have heterogeneity which were not explicitly assessed or modeled for the Shenandoah SWCD. The opportunity costs from farm to farm and even field to field may differ within the district. Across the Bay watershed, the opportunity costs would likely vary even further. This analysis assumed one opportunity cost value for each land use type (hay, crop, or pasture) for the Shenandoah SWCD. Additional research on the variance in opportunity costs would improve the analysis for this and wider geographic scale studies.

Beyond the Shenandoah SWCD, other districts will have varying potential income from nutrient credits based on the fate and transport of nitrogen and phosphorus from the field to the Bay. This dissertation research utilized the specific effectiveness values incorporating transport factors for BMPs on each land use for the Shenandoah SWCD. The Chesapeake Bay Model uses estimates for the fate and transport of nitrogen and phosphorus with regional transport factors estimated by the EPA (2010) which accounts for geologic setting, soil type, precipitation, and stream-segment influences for each county in the watershed. Figure 14 shows the regional nutrient transport factors for nitrogen and phosphorus in the Chesapeake Bay watershed.

The significance of these factors is that they directly influence the potential nutrient credit income earned by any farmer. For the Shenandoah SWCD, the nitrogen and phosphorus transport factors are 1.2 and 1.7, respectively. This factor is incorporated into the modeling of effectiveness for Shenandoah SWCD (lbs/acre). The factors on the map may appear counterintuitive if considering only distance from the Bay; however, the other non-linear factors mentioned above also influence the transport factors.

Comparing other regions in the watershed, transport factors are as low as 0.5 and as high as 2.0 for both nitrogen and phosphorus. When incorporating these values into the analysis of net benefits for each of the BMPs, the factors do influence a farmer’s potential income. For example, early planted cover crops in the Shenandoah SWCD can expect a cost of approximately $23.28 per acre. In a county with a regional transport factor of 0.5, a farmer would expect higher net costs at $25.06 (based on analytical assumptions). In a county with a regional transport factor of 2.0, the farmer's cost would be less at $21.25. Overall, though, an evaluation of the lowest and highest transport factors does not influence whether net costs are positive or negative in this analysis.

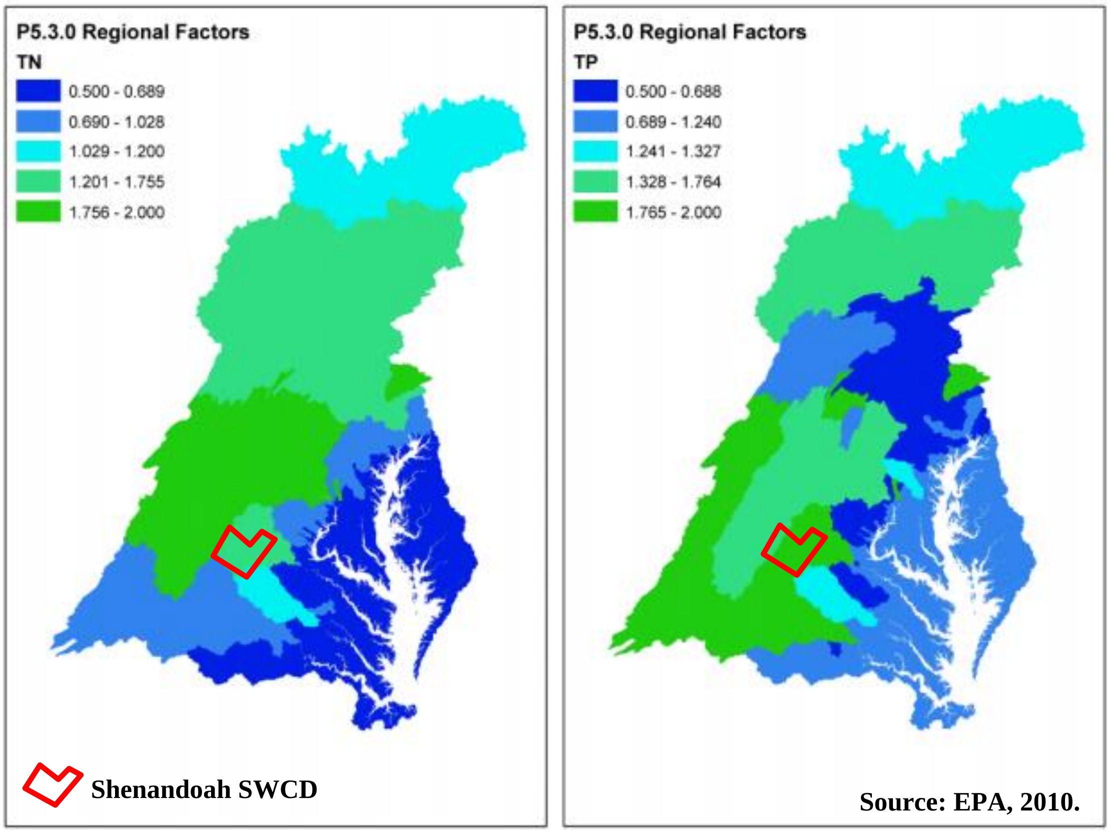

Figure 14. Regional Nutrient Transport Factors

If considering farmers' willingness to pay in counties other than the Shenandoah SWCD or multiple counties, incorporating transport factors may have an influence and should be incorporated into future analyses. There are multiple types of heterogeneity that affect farmer willingness to participate in nutrient credit markets. This research focused on the heterogeneity in installation costs of agricultural BMPs. Table 37 summarizes other categories of heterogeneity that would likely influence farmer willingness to participate in nutrient credit markets.

Table 37. Types of Heterogeneity that influence Farmer Willingness to Participate in Nutrient Credit Market

Heterogeneity Category	Factors
Agricultural BMP Costs	
Installation Costs	Location, Soil Type, Availability of Equipment, Material Costs, Labor Costs, Land Condition, Type of Crop (cover crop), Water Availability (exclusion), Tree Density (riparian buffer)
Maintenance Costs	Precipitation, Presence/Absence of Pests
Opportunity Costs	Type of Crop (Field or Adjoining Field), Quality of Soil
Agricultural BMP Benefits	
Nutrient Transport Factors	Location, Soil Type, Geologic Setting, Land-River Segment, Precipitation

The installation costs within the Shenandoah SWCD and, to the extent that this district is representative, across Virginia were the focus of this dissertation. To provide hybrid scale approaches to assess water quality trading potential in the United States, additional research outside of the scope of the current analysis is needed. For other locations in the Chesapeake Bay watershed, field-level costs (or samples from representative communities) are required to conduct similar analyses as the one executed for the Shenandoah SWCD in Virginia.

The current analysis could be refined with data on the heterogeneity of both operating and opportunity costs.

Additional research that would improve assessment for the potential for nutrient trading in the Chesapeake Bay watershed includes estimating heterogeneity in wastewater treatment facility costs and urban stormwater management BMPs. Conducting analyses of these costs in more detail would enrich the understanding of, hence the feasibility of the potential nutrient trading market.

A second area for additional research is the factors associated with market design and how they influence farmers, wastewater treatment facilities, and other market participants. For example, transactions costs associated with making a trade are not well understood in Virginia. Other factors, such as verification procedures or who is allowed to inspect a field may influence farmers' willingness to participate in the market. A survey based in the Chesapeake region would provide more relevant input for this market.

These two areas of additional research pertain to the design of the market and cost aspects. Beyond this line of research, there are also requirements for better information on agricultural BMP efficacy, TMDL load limits and the correlation with water quality, and the benefits (both direct and indirect) of achieving the TMDL.

Final Thoughts

By not considering the heterogeneity in costs, previous economic assessments have greatly overestimated trading potential in the Chesapeake Bay. This dissertation identified key causes leading to a lack of trading including higher than estimated agricultural BMP costs, the barrier of a too low fixed nutrient credit price, and the requirements of the baseline BMPs and their associated costs. This solution-oriented analysis suggests allowing the price to float and revising the regulations to allow baseline BMPs to earn credits which could stimulate significant market activity and support the implementation of the Chesapeake Bay TMDL.

While this dissertation focused on the Shenandoah SWCD in Virginia, this region is representative of Virginia agriculture at large and the lessons learned from this case study should hold for the state as a whole. Additionally, the analysis can be scaled to other states and jurisdictions in the Chesapeake Bay watershed. Significantly, this research illustrates the need to more closely examine the field-level costs in other states to better understand how much voluntary contributions of nutrient reduction from agriculture can be relied on to meet the TMDL. Finally, across the United States to address the challenge of impaired water quality due to agricultural non-point source nutrient pollution, the findings of this research support a better understanding of the actual costs of implementing agricultural BMPs and the influence of market design factors.

APPENDIX 1: MEMORANDUM OF UNDERSTANDING

The Shenandoah SWCD provided access to output from the aggregated cost database as well as the ability to review the physical files in the SWCD office. The information on individual farmers was only made available to be viewed by the researcher; it was not allowed to be reported in raw form in the dissertation or shared with anyone else other than the researcher. The Director of the SWCD and Ms. Pindilli developed and signed an agreement to that end (see below). Additionally, Ms. Pindilli signed a Volunteer Services Agreement for Natural Resources Agencies form (OMB Form 0596-0080).

MEMORANDUM OF AGREEMENT

TO:	Megen Dalton, District Manager Shenandoah Valley Soil & Water Conservation District 1934 Deyerle Avenue, Suite B Harrisonburg, VA 22801
FROM:	Emily Pindilli, PhD Candidate George Mason University 4400 University Dr. Fairfax, VA 22030
SUBJECT:	Dissertation Research on the Heterogeneity of Agricultural BMP Costs
DATE:	May 6, 2014
CC:	Dr. Dann Sklarew, Advisor George Mason University 4400 University Dr Fairfax, VA 22030

Ms. Emily Pindilli is a PhD candidate in the Environmental Science and Policy Program at George Mason University (GMU) in Fairfax, Virginia. She has a background in economics and is interested in the nexus of economics and science to improve decision-making. Ms. Pindilli enjoys Virginia's natural and human heritage of rivers, mountains, and rolling agricultural fields. When the Chesapeake Bay Total Maximum Daily Load decision was made in 2009, Ms. Pindilli was pursuing her master's at GMU. She followed the progress of state implementation planning, consideration of integrating market-based approaches to reduce non-point source pollution, and the lackluster trading that has occurred in nutrient markets in the watershed. Ms. Pindilli saw this as an opportunity to analyze why there weren't as many trades as had been expected and designed a PhD research project in hopes to advance policy to provide better outcomes for water quality in the Chesapeake Bay.

To assess nutrient trading in the Chesapeake Bay watershed, Ms. Pindilli's research prospectus is focused on conducting an economic analysis of the potential contribution of 'voluntary' reductions of nutrients from agricultural nonpoint sources of pollution to the Chesapeake Bay originating in the state of Virginia. Her objective is to address the lack of an in-depth assessment of field level costs for implementing agricultural best management practices (BMPs) in previous economic analyses of nutrient trading in the watershed. The research has three high level objectives: 1) to assess the heterogeneity in costs of implementing and maintaining BMPs at the field level; 2) to estimate the magnitude of nutrient reductions from agriculture in Virginia based on the field level cost analysis and Virginia's trading program statutory requirements, ceteris paribus; and 3) evaluate an alternative scenario of nutrient reduction based on the sensitivity of farmers to commodity prices. The study will consider the economic and physical factors associated with farms and build on a vast base of literature on the physical aspects of nonpoint source pollution abatement.

To conduct this research, Ms. Pindilli requires access to detailed cost data on farmer implementation of BMPs. The Shenandoah Valley Soil and Water Conservation District (SWCD) has files on this type of detailed data on what farmers actually paid for the implementation of BMPs. The Shenandoah Valley SWCD has agreed to provide Ms. Pindilli access to the data with the understanding that she will evaluate the cost information without reporting out any results that would compromise the private, personal, or proprietary information of any individual farmer. To achieve this, Ms. Pindilli's approach is to utilize the data to develop a regression equation based on the raw data. This equation will be reported along with associated statistics, such as goodness of fit, but the raw data will not be provided in the dissertation or to any other individual. Ms. Pindilli will use the regression equation to 'predict' whether or not farms in Virginia would be willing to implement BMPs. This will provide the basis of a model to estimate the quantity of nutrients that will be reduced in Virginia from meeting both baseline requirements and those that generate nutrient credits.

Ms. Pindilli is greatly appreciative of the Shenandoah Valley SWCD for their willingness to help, their time, and their expertise; all of which helped shape Ms. Pindilli's research approach. Ms. Pindilli will take whatever measures possible to reduce the burden on the office during discussions, in accessing the data, and any follow-up. Ms. Pindilli will ensure to give proper credit and/or reference the Shenandoah Valley SWCD in her dissertation and any publications. She will give the office an opportunity to review her draft materials to ensure there are no issues with the level of aggregation of data in the document. It would be Ms. Pindilli's pleasure to present her findings to the office and/or Board as appropriate; it is anticipated that she will have initial results late in 2014 and will be defending her dissertation early spring (~March) of 2015. Ms. Pindilli will provide a copy of the final dissertation after defense.

________________________ ________________

Emily Pindilli Date

________________________ ________________

Megen Dalton Date

APPENDIX 2: INSTITUTIONAL REVIEW BOARD HUMAN SUBJECTS RESEARCH DETERMINATION FORM

GEORGE MASON UNIVERSITY

Institutional Review Board
Human Subjects Research Determination Form

Instructions:

1. Use this form to evaluate the need for IRB review.
2. If needed, submit this form via IRBnet to the Office of Research Integrity & Assurance for an official letter.
3. Note: If your project must be submitted to the FDA or held for inspection by the FDA you must complete the standard IRB application form.

1. Investigator Contact Information/Study Type

Principal Investigator

Name: Emily Pindilli Department: Environmental Science and Policy

Mail Stop: N/A Phone: E-mail:

Co-Investigator/Student Researcher

Name: Department:

Mail Stop: Phone: E-mail:

Study Type: ☐ Faculty/Staff Research √Doctoral Dissertation ☐ Masters Thesis

☐ Student Project (**Specify** Grad or Under Grad)

☐ Other {Specify}

2. Determination categories:

a. Does your research:

i. Involve living individuals? ☐ Yes √ No

ii. Involve obtaining <u>either</u> of the following: √ Yes ☐ No

- Data through intervention or interaction with the individuals*
- Identifiable private information**

If YES is checked for both questions continue to section b; if NO is checked for either question the activity does not meet the definition of human subjects research that requires IRB review.

b. Is your project:

i. A systematic investigation: an activity that involves a prospective plan which incorporates data collection (quantitative or qualitative), and data analysis to answer a question. ☐ Yes ☐ No

ii. Designed to develop or contribute to generalizable knowledge: designed to draw general conclusions (knowledge obtained from study may be applied to populations outside the study population), inform policy, or generalize findings. ☐ Yes ☐ No

If YES is checked for both questions, submit a standard IRB application form; do not submit this form. If NO is checked for either question the activity does not meet the definition of human subjects research that requires IRB review.

3. Title/Summary *(Only complete this section if you are submitting form for official letter)*

Title: An Economic Analysis Of The Potential Contribution Of 'Voluntary' Reductions Of Nutrients From Agricultural Non-point Sources Of Pollution To The Chesapeake Bay Originating In The Shenandoah Soil And Water Conservation District, Virginia

Please provide a brief summary of the research: This study addresses the lack of an in-depth assessment of field-level costs for implementing agricultural best management practices (BMPs). An economic analysis of the potential contribution of 'voluntary' reductions of nutrients from agricultural non-point sources of pollution to the Chesapeake Bay originating in the Shenandoah Soil and Water Conservation District (Shenandoah SWCD), Virginia was conducted. The research has three high level objectives: 1) to assess the heterogeneity in costs of implementing BMPs at the field-level; 2) to estimate the magnitude of potential nutrient reductions possible from agriculture in the Shenandoah SWCD, Virginia based on the field-level cost analysis and Virginia's trading program statutory requirements, *ceteris paribus*; and 3) to evaluate a possible alternative scenario of nutrient reduction based on the sensitivity of farmers to allowable BMPs. The study considers the economic and physical factors associated with farms and builds on a vast base of literature on the physical aspects of non-point source pollution abatement. The heterogeneity in costs of six BMPs applied in the Shenandoah SWCD over the course of six years is analyzed. Interviews with experts are a component of the information gathering. Experts in agricultural economics and ecology are asked about information relevant to the research.

*Intervention, as it pertains to research involving human subjects defined in 46.102 within the Human Subject definition – includes both:

- physical procedures by which data are gathered (for example, venipuncture) and
- manipulations of the subject or the subject's environment that are performed for research purposes

Interaction, as it pertains to research involving human subjects defined in 46.102 within the Human Subject definition – includes communication or interpersonal contact between investigator and subject

** Individually Identifiable, as it pertains to research involving human subjects defined in 46.102 within the Human Subject definition – the identity of the subject is or may be readily ascertained by the investigator or readily associated with the information. In addition, OHRP generally considers private information or specimens to be individually identifiable when they can be linked to specific individuals by the investigator(s) either directly or indirectly through coding systems (according to the Guidance on Research Involving Coded Private Information or Biological Specimens).

APPENDIX 3: DESCRIPTIVE STATISTICS RESULTS

	Best Management Practices						
	CREP Riparian Forest Buffer Planting	Livestock Exclusion with Riparian Buffers for TMDL Implementation	Stream Exclusion with Grazing Land Management	Permanent Vegetative Cover on Cropland	Harvestable Cover Crop	Small Grain Cover for Nutrient Management	Animal Waste Control Facilities
Number	60	11	30	83	802	$601	50
Minimum	$179	$255	$71	$54	$5	$6	$9
Maximum	$1,194	$2,566	$2,127	$413	$149	$119	$1,011
Mean	$760	$1,114	$761	$240	$56	$53	$215
Median	$796	$1,004	$562	$251	$53	$50	$95
Standard Deviation	$178	$713	$527	$88	$17	$15	$237
Interquartile Range	$205	$909	$678	$120	$15	$18	$264
Variance	$32,100	$559,455	$286,763	$7,877	$277	$227	$57,228
Coefficient of Variance	23%	64%	69%	37%	30%	28%	110%

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