FINAL REPORT

Building Capacity to Analyze the Economic Impacts of Nutrient Trading and Other Policy Approaches for Reducing Agriculture's Nutrient Discharge into the Chesapeake Bay Watershed
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Executive Summary

This report summarizes the results of our work on Cooperative Agreement No. 58-0111-11-006, "Building Capacity to Analyze the Economic Impacts of Nutrient Trading and Other Policy Approaches for Reducing Agriculture's Nutrient Discharge into the Chesapeake Bay Watershed." This a collaborative project undertaken with the USDA Office of the Chief Economist to enhance capacities to characterize the economic implications of nutrient credit trading and other policy approaches (e.g. USDA working lands and land retirement programs, compliance programs) for reducing agriculture's nutrient discharge into the Chesapeake Bay Watershed. The project utilized data on the costs of agricultural BMPs included in the USEPA Chesapeake Bay model, and parameters from the Chesapeake Bay model that indicate the effectiveness of alternative BMPs located in geographic management units defined by the intersection of relevant political jurisdictions with hydrological mapping units from the USEPA Chesapeake Bay model. These data were used to: (1) estimate the agricultural costs of the Watershed Implementations Plans (WIPs) developed by the states in the Chesapeake Bay Watershed to comply with the US Environmental Protection Agency's 2010 Chesapeake Bay Total Maximum Daily Load (CB-TMDL); (2) estimate agricultural cost savings that could be realized by more efficient selection of agricultural Best Management Practices (BMPs) and spatial targeting of BMP implementation than required by the WIPs; and (3) estimate potential gains from nutrient trading. In addition to these policy analyses, the results and algorithms developed as part of this agreement can be used to help NRCS determine funding needs and inform targeting strategies. The products of this agreement also include a procedure for assessing BMP implementation that could be used by federal or state authorities to prioritize BMP types and locations based on cost-effectiveness.

Lack of specificity in the WIPs about the exact timing of BMP implementation results in various plausible time paths. Using the assumptions in this study, we estimate the present value of the cost of implementing the required agricultural BMPs between 2011 and 2025 in 2010 dollars to be about $3.6 billion. Our results show that significant cost savings can be realized through better BMP selection and spatial targeting. These results also imply that potential gains from nutrient trading are substantial, with areas closer to the Bay likely becoming low-cost suppliers of credits. Of course, gains are dependent on how state and Bay-wide trading programs are designed and implemented.

Introduction

In December 2010, the US Environmental Protection Agency (USEPA) issued the Chesapeake Bay Total Maximum Daily Load (TMDL). The TMDL specifies reductions of nitrogen, phosphorus, and sediment across Delaware, Maryland, New York, Pennsylvania, Virginia, West Virginia, and the District of Columbia, and sets pollution limits necessary to meet applicable water quality standards in the Bay and its tidal rivers and embayments. It calls for all pollution control measures needed to fully restore the Bay and its tidal rivers to be in place by 2025, with at least 60 percent of the actions completed by 2017. The TMDL is required under the federal Clean Water Act and responds to consent decrees in Virginia and the District of Columbia from the late 1990s. It is the largest TMDL ever developed by the EPA.

With 22% of the Bay's watershed land area, agriculture is the second largest land use (following forests and open wooded areas with 69% percent of the land area). Agricultural activities are estimated to contribute approximately 44% percent of nitrogen and phosphorus loads, and 65% of the sediment loads delivered to the Bay, making it the largest economic source of nutrients and sediments to the Bay. The TMDL calls for reducing nitrogen, phosphorous, and sediment loads from agriculture by 37%, 29%, and 28%, respectively, relative to 2009 baseline loads and by 34%, 29%, and 22%, respectively, relative to 2011 baseline loads. The allocation of these reductions varies across political jurisdictions and major basins. The means by which agricultural reductions are to be achieved in each jurisdiction are described in Watershed Implementation Plans (WIPs) developed by the six Bay states in collaboration with the EPA.

This project was fundamentally motivated by interest in the potential for water quality credit trading to reduce TMDL compliance costs. Social costs savings from pollution trading are the difference between social compliance costs "with" and "without" trading. Compliance costs incurred under existing or proposed regulatory allocations of pollution control and compliance costs typically define "without trading" costs (or the regulatory baseline costs). Traditional air and water pollution regulations entail imposing periodic (e.g. annual) maximum limits on emissions from specific sources (e.g. smokestacks, outfalls), and requiring that those limits be met at the source. The requirement that limits are met at the source prevents emissions reductions from one source being used to meet the requirements of another. Prohibiting the use of emissions reductions from one source to offset emissions from another serves no environmental purpose if environmental conditions are unaffected by the offset. The inability to use offsets increases the costs of pollution control when the incremental cost of pollution abatement differs between sources. Emissions trading allows for flexibility in how emissions limits can be met. With trading, a source may meet a regulatory limit on its emissions in part or in whole (depending on trading rules) by acquiring offsetting emissions reductions from other sources. The costs saving relative to the regulated allocation are often called the *gains from trade* (Shortle 2012).

Estimates of the gains from emissions trading are classified as *ex ante* and *ex post* (Tietenberg and Johnstone 2004). The former are predictions of savings from trading prior to the implementation of trading programs. The latter estimate gains based on cost savings actually realized after implementation. Given that trading with agriculture is in the implementation stages in the Bay region, this study is of the *ex ante* type. We estimate the costs of compliance with the WIPs in this *ex ante* assessment as the “without trading” compliance costs. The appropriate estimate of compliance costs “with trading” is the costs that would be realized after the opportunity to trade has had its full impact on the allocation of pollution control. Under the assumption that trading will minimize pollution abatement costs, some researchers have used estimates of the costs of compliance with pollution control targets when achieved at the lowest possible cost as the “with trading” compliance cost. Research indicates that this approach is biased towards underestimating compliance costs “with trading,” and consequently overestimating the gains from trade because of inefficiencies that occur in environmental markets (e.g., Nguyen et al. 2013). The estimated difference between baseline costs and the estimated least cost allocation is best viewed as an upper bound on *potential gains from trade*.

For there to be potential gains from trade for agriculture, the allocation of pollution control under the WIPs must be economically inefficient. Otherwise, there could be no potential costs savings from changes in the allocation of pollution control. To explore the potential for gains, we conducted simulations to determine if the costs of compliance with the agricultural load allocations required by the TMDL could be achieved at lower cost than what we estimate for the WIPs. The simulations entailed searching for portfolios of BMP types and locations that minimized agricultural nonpoint source (NPS) costs. The simulations allow us to estimate potential gains from trade.

The focus of the tasks above is on costs of pollution control in agriculture. Under existing and emerging rules, it is expected that trading would largely entail sales of nutrient and sediment credits produced by agricultural BMP adoption to regulated point sources (Ribaudo

2013). To examine the potential for such a market, we derive supply curves for agricultural credits under alternative assumptions about credit baselines and examine the willingness to pay for credits relative to the marginal costs.

We find that the cost of implementing the agricultural BMPs required by the WIPs between 2011 and 2025 totals about $3.6 billion (in 2010 dollars). The annual cost associated with full implementation of all WIP BMPs from 2025 onwards (2025 annual costs) is about $900 million. Our results show that significant cost savings can be realized through BMP selection and spatial targeting that take into account the relative cost-effectiveness of alternative BMP types and locations. These results also imply that potential gains from nutrient trading are substantial, with areas closer to the Bay likely becoming low-cost suppliers of credits. Of course, gains are dependent on how state and Bay-wide trading programs are designed and implemented.

Agricultural Nonpoint Pollution Control WIP Costs

In this section we examine the costs of compliance with the WIPs for agricultural NPS. We provide an estimate of the present value of the costs of installing BMPs needed to comply with the WIP by 2025. We also present estimates of the annualized costs of the fully implemented BMPs required by the WIPs. The section is divided into subsections describing the WIPs, geographic management units, costs concepts, data sources, methods and assumptions used in the analysis, and the results.

Agricultural WIPs

While we take the WIPs as the "without trading" pollution control allocation for agricultural NPS under the TMDL, it should be noted that the WIPs do not provide a well-defined set of regulatory requirements for agricultural NPS analogous to those faced by point sources subject to permit requirements under the National Pollution Discharge Elimination System (NPDES). The 1972 Clean Water Act (CWA) and subsequent amendments divided authority for point source (PS) and nonpoint source pollution (NPS) control between federal and state authorities. The CWA made PS pollution control a federal responsibility, though it allowed for the delegation of this authority to the states. PS controls are implemented through non-tradable NPDES effluent permits. Emerging water quality trading programs allow point sources to meet applicable effluent limits using pollution reduction credits acquired from other sources. Under federal regulations, large concentrated animal feeding operations (CAFOs) that discharge directly to surface waters though a pipe or ditch are treated as point sources and must obtain NPDES permits. However, agricultural NPS is not similarly regulated. In contrast to PS, the CWA gave responsibility for the control of agricultural NPS pollution to the states. With some exceptions and to varying degrees, the states have largely relied on voluntary compliance strategies for agricultural NPS control, supported to varying degrees by state and federal programs for technical and financial assistance for agricultural BMP adoption, rather than comprehensive regulation of individual polluters (Shortle et al. 2012).

Under the TMDL, Chesapeake Bay load and wasteload allocations are subdivided by jurisdiction and major river basin. These jurisdictions include Delaware, the District of

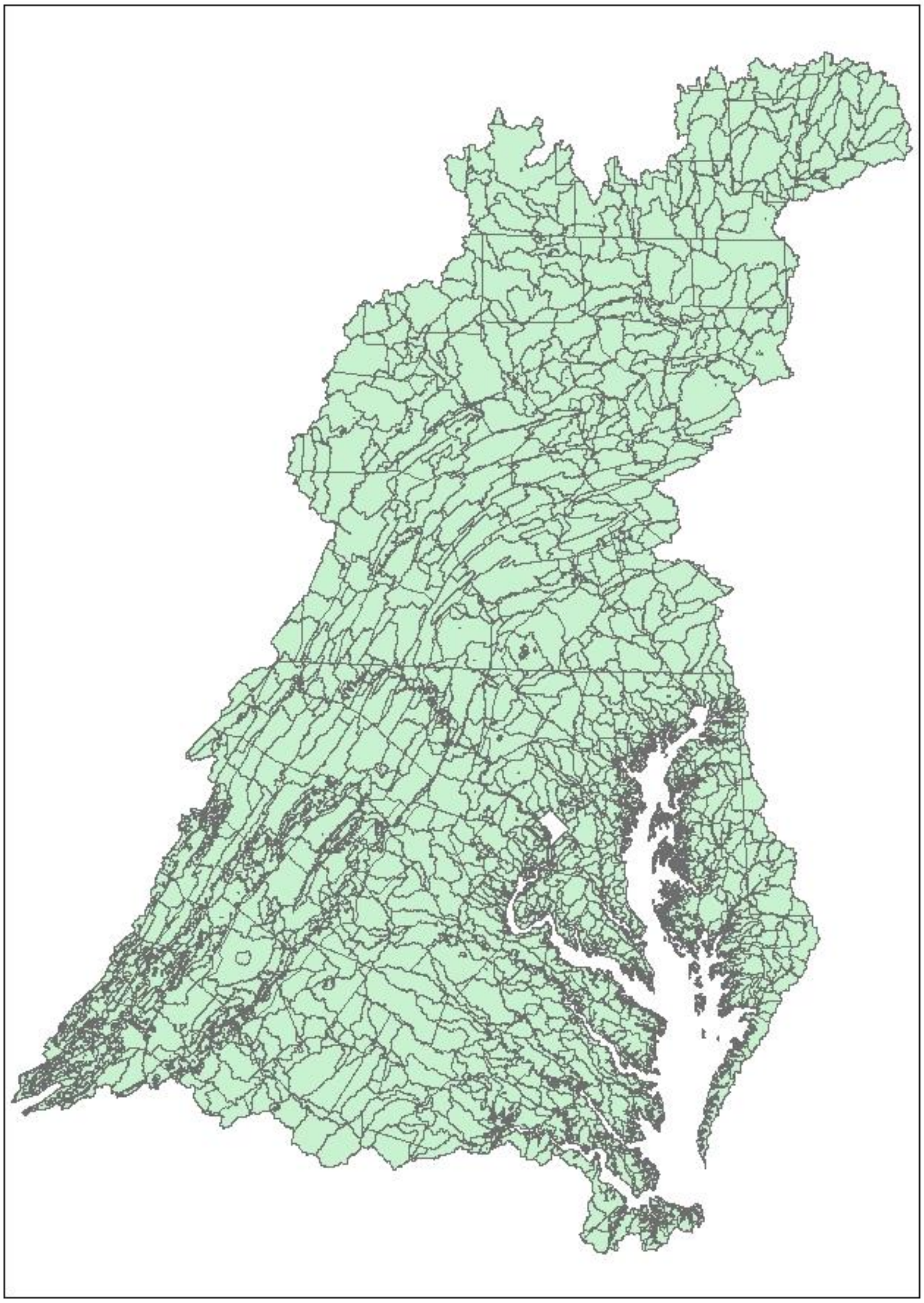
Columbia, Maryland, New York, Pennsylvania, Virginia, and West Virginia. The District of Columbia is not included in our analysis because it has no agricultural lands. Each jurisdiction submitted Phase I and Phase II WIPs, which outline how each jurisdiction will achieve their nitrogen, phosphorus, and sediment pollution allocations for every sector. For agriculture the WIPs consist of lists of agricultural Best Management Practices (BMPs) that the states propose to have installed to meet their agricultural load allocations. Importantly in this context, the states' WIPs provide only limited details about when and where specific BMPs are implemented within jurisdictions. Both of these matter to the costs of the WIPs. Our assumptions about timing and location are described below.

Geographic Management Units

While the states' WIPs provide some information about where designated BMPs would be located, more detailed information is required to determine if the WIPs would meet the load allocations. This is because the specific location of pollution control activities within the watershed is a major factor determining the impact on pollution loads. The major tool used to assess the impact of the WIPs on pollution loads and to assess compliance with the TMDL is the Chesapeake Bay Model (CBM). We utilize data and geographic management units from the Chesapeake Bay Model Phase 5.3.2 in this study. Any references to the CBM refer to this version of the model.

The CBM is a hydrological model that simulates and projects pollutant loads and how they move over and through the land and water in the Chesapeake Bay Watershed (CBW). Input data include monitoring data from streams and rivers throughout the CBW, climate data, hydrogeomorphic conditions, and sector-specific variables. Land-river segments are the base modeling unit for the CBM. Figure 1 below shows phase 5.3.2 land-river segments within the CBW. Counties form the basis of the land segmentation, with some counties divided further as a result of land-based criteria within counties affecting nutrient flows. Federal lands within each county are treated as separate land units. The river segmentation simulates river reaches of similar discharges of approximately 100 cubic feet per second. The intersection of the land and river segments results in the land-river segmentation for the CBM. Nutrient flows are modeled within each of these land-river segments in the Bay Model. After eliminating those land-river segments with no agricultural land, there were 2,426 land-river segments in our analysis. They include 28 in Delaware, 671 in Maryland, 143 in New York, 582 in Pennsylvania, 881 in Virginia, and 121 in West Virginia (USEPA 2010). The CBM identifies land according to sector-specific land uses. For agriculture, these land uses include animal feeding operations, row crops, hay, pasture, degraded riparian pasture, and nurseries. The CBM also explicitly models whether a land-use is high-till or low-till for row crops and hay, and whether a land use utilizes nutrient management for row crop, hay, and pasture land. This results in 16 agricultural land uses, excluding concentrated animal feeding operations, which are treated as point sources of pollution by USEPA and in the Bay Model (USEPA 2010).

Figure 1. Phase 5.3.2 Land –River segments in the Chesapeake Bay Watershed



The CBP uses a proportional allocation rule to distribute WIP BMPs across land-river segments. The rule allocates BMPs according to the percentage of applicable land use acres within each land-river segment modeling unit. The CBM is used to calculate load reductions associated with the WIP BMPs. If the load allocations for agriculture are not met, the CBM automatically applies trading ratios between pollutants in an attempt to meet targets for each pollutant. For example, if there is more N reduction than necessary, some pounds of N may be "traded" for extra pounds of P reduction according to pre-defined trading ratios within the model. Multiple scenarios have been run for each jurisdiction as implementation has progressed from the Phase I to the Phase II WIPs.

Agricultural BMP Costs

The cost of a BMP can be calculated from three perspectives: the cost to the farmer, the cost to the government, and the cost to society. All three types are of interest in this project. The social cost of a BMP installed to reduce pollution of the Chesapeake Bay is the reduction in farm income, net of public subsidies or tax payments, plus (or minus) any welfare losses (gains) resulting from increased (reduced) prices of agricultural products or reduced (increased) prices for specialized agricultural resources such as farmland, less any social welfare gains resulting from ancillary environmental improvements outside of the Bay proper (these ancillary environmental gains could also be counted as benefits of pollution control rather than as negative costs). Private costs are the changes in net farm income from BMP installation. Social costs are the appropriate costs for considering the societal welfare gains or losses while private costs are appropriate for considering impacts on the agricultural sector. Private costs are also crucial to considering incentives for trading, since farmers will respond to private benefits and costs when making decisions about trading. By government costs we refer to government expenditures for BMP implementation. These would include financial assistance provided directly to farmers, and expenditures on technical assistance for BMP implementation.

The primary data source for BMP costs used in this study is estimates made available to the project by the USEPA Chesapeake Bay Program (CBP). These estimates were developed for the CBP by Abt Associates for BMPs in the Phase II WIPs (Abt Associates/USEPA 2012). For quality assurance, and to ensure an acceptable degree of consistency between our cost estimates and those developed by Abt Associates, we communicated extensively with representatives of Abt Associates, the Chesapeake Bay Program, and the USDA OCE on the costs of individual BMPs.

The primary data source for the Abt/USEPA cost estimates is Natural Resource Conservation Service (NRCS) financial assistance payment schedules. These payment schedules list NRCS payment rates for eligible practices under applicable programs. Eligible practices and payment rates do not necessarily align across jurisdictions. The rule of thumb adopted by the USEPA for Delaware, Maryland, New York, Pennsylvania, and West Virginia is that the cost to NRCS is 75% of the cost to the farmer, so that farmer costs can be calculated as NRCS costs divided by 0.75. The payment schedule for Virginia lists total cost estimates, so unit costs are not divided by the assumed payment share rate of 75%.

A 75% share rate may be roughly suitable for BMPs that are consistent with a cost-sharing model in which BMPs have some private benefit to the farmer, but not enough of a benefit to cover the entire cost. However, many BMPs do not fit this model. Some BMPs will not increase the present value of farm income and thus have no direct economic benefits to farmers (i.e. increased profitability). For example, installing a riparian buffer reduces crop or pasture land and takes away the income that would have been earned from that land. In these cases, the farmer’s cost is the out-of-pocket expense plus any opportunity costs resulting from changes in the farm operation. If installation is purely voluntary, profit-maximizing farmers will not be willing to adopt unless their costs are fully covered by NRCS payments. In these cases, NRCS payment schedules can be viewed as an upper bound on the cost to the farmer, not 75% of the cost.

Other BMPs may increase farm profits. For example, conservation tillage can increase profitability by reducing input costs and through long term gains in productivity. In these cases, the net cost to the farmer may be zero or negative, and need not bear any relationship to NRCS payment schedules.[1]

In general then, NRCS payment schedules provide information on the costs of BMP implementation (net of technical assistance and administrative overhead) to NRCS when financed by USDA programs, but overestimate private costs. Estimating the latter is beyond the scope and resources of this project. Accordingly, we view Abt/USEPA cost estimates for most practices as upper bounds on the actual costs of WIP BMPs, excluding technical assistance and administrative overhead costs.

The BMP definitions used by Abt Associates, and by this study, generally correspond to the Chesapeake Bay Watershed Model (CBM) definitions. These BMPs are listed in Table 1. Our costs estimates rely on the Abt/USEPA BMP unit cost estimates, with limited adjustments and exceptions. These adjustments, exceptions, and other specific details of the BMP cost estimates, and comments on the reliability of the BMP costs data are presented in Appendix C. Cost estimates were confined to well-established BMPs, and thus largely excluded interim or

[1] For these BMPs, profit-maximizing farmers would presumably adopt them anyway even without an NRCS payment.

newly developed BMPs that have not yet been approved for credit within the CBM. Unit costs of BMPs are listed in Table 2.

Table 1. BMP Descriptions

BMP	BMP Description
Alternative Watering	Use of permanent or portable livestock water troughs placed away from the stream corridor. The source of water supplied to the facilities can be from any source including pipelines, spring developments, water wells, and ponds. In-stream watering facilities such as stream crossings or access points are not considered in this definition.
Ammonia Emissions Reduction – Alum	Litter amendments like alum suppress the formation of ammonia from ammonium in litter. Biofilters attached to animal enclosure ventilation systems detoxify ammonia. Lagoon covers prevent volatilization from loss due to wind.
Ammonia Emissions Reduction - Bio & Lagoon	
AWMS - Livestock	Designed for proper handling, storage, and utilization of wastes generated from AFOs; reduced storage and handling loss is conserved in the manure available for land application.
AWMS - Poultry	
Barnyard Runoff	Control runoff from barnyard areas (e.g., roof runoff control, diversion of clean water from entering the barnyard, and control of runoff from barnyard areas).
Capture & Reuse	Capture and reuse entails the use of lined return ditches or other collections methods to lined holding ponds that retain excess irrigation water runoff and capturing stormwater runoff.
Carbon Sequestration	Conversion of cropland to hay land (warm season grasses). The hay land is managed as a permanent hay land providing a mechanism for sequestering carbon within the soil.
Commodity Cover Crops	May be harvested for grain, hay or silage and they may receive nutrient applications, but only after March 1 of the spring following their establishment.
Conservation Plan	Combination of agronomic, management and engineered practices that protect and improve soil productivity and water quality, and prevent deterioration of natural resources on all or part of a farm. Plans may be prepared by staff working in conservation districts, natural resource conservation field offices or a certified private consultant. In all cases the plan must meet technical standards.
Conservation Tillage	Planting and growing crops with minimal disturbance of the surface soil. Conservation tillage requires two components, (a) a minimum 30% residue coverage at the time of planting and (b) a non-inversion tillage method. No-till farming is a form of conservation tillage in which the crop is seeded directly into vegetative cover or crop residue with little disturbance of the surface soil. Minimum tillage farming involves some disturbance of the soil, but uses tillage equipment that leaves much of the vegetation cover or crop residue on the surface.
Continuous No-Till	Crop planting and management practice in which soil disturbance by plows, disk or other tillage equipment is eliminated. CNT involves no-till methods on all crops in a multi-crop, multi-year rotation.
Cover Crops	The planting and growing of cereal crops (non-harvested) with minimal disturbance of the surface soil. Different species are accepted as well as, different times of planting (early, late and standard), and fertilizer application restrictions.
Cropland Irrigation Management	Decreases climatic variability and maximizes crop yields. The potential nutrient reduction benefit stems not from the increased average yield (20-25%) of irrigated versus non-irrigated cropland, but from the greater consistency of crop yields over time matched to nutrient applications. This increased consistency in crop yields provides a subsequent increased consistency in plant nutrient uptakes over time matched to applications, resulting in a decrease in potential environmental nutrient losses.
Dairy Precision Feeding	Reduces quantity of phosphorous and nitrogen fed to livestock by formulating diets within 110% of Nutritional Research Council recommended level to minimize the excretion of nutrients without negatively affecting milk production.
Decision Agriculture	Information and technology based management system that 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.
Enhanced Nutrient Management	The nutrient management rates of nitrogen application are set 35% higher than crop needs to ensure nitrogen availability under optimal growing conditions. An incentive or crop insurance is used to cover the risk of yield loss.

BMP	BMP Description
Forest Buffers	Linear wooded areas along rivers, stream and shorelines. The recommended buffer width for riparian forest buffers (agriculture) is 100 feet, with a 35 feet minimum width required.
Grass Buffers	Linear strips of grass or other non-woody vegetation maintained between the edge of fields and streams, rivers or tidal waters that help filter nutrients, sediment and other pollutant from runoff. The recommended buffer width for riparian forests buffers (agriculture) is 100 feet, with a 35 feet minimum width required.
Horse Pasture Management	Stabilizing overused small pasture containment areas (animal concentration area) adjacent to animal shelters or farmstead.
Land Retirement	Takes marginal and highly erosive cropland out of production by planting permanent vegetative cover such as shrubs, grasses, and/or trees.
Liquid/Poultry Manure Injection	The subsurface application of liquid manure (from cattle, swine, and poultry) reduces nutrient losses for both surface runoff and ammonia emissions. This practice is indicative of low disturbance soil injection systems and is not appropriate for tillage incorporation or other post surface application incorporation methods.
Loafing Lot Management	Stabilization of areas frequently and intensively used by people, animals or vehicles by establishing vegetative cover, surfacing with suitable materials, and/or installing needed structures (does not include poultry pad installation).
Manure Transport - Inside CBWS **Manure Transport - Outside CBWS**	Manure is transported by truck from the county of origin to another or out of the watershed. Manure transported to another county in the watershed results in increased manure mass in the receiving county.
Mortality Composters	A physical structure and process for disposing of dead livestock. Composted material is combined with poultry litter and land applied using nutrient management plan recommendations.
Nutrient Management	Nutrient management plan implementation (crop) is a comprehensive plan that describes the optimum use of nutrients to minimize nutrient loss while maintaining yield. A NMP details the type, rate, timing, and placement of nutrients for each crop. Soil, plant tissue, manure and/or sludge tests are used to assure optimal application rates. Plans should be revised every 2 to 3 years.
Poultry Phytase	Phytase is an enzyme added to poultry-feed that helps poultry absorb phosphorus. The addition of phytase to poultry feed allows for more efficient nutrient uptake by poultry, which in turn allows decreased phosphorus levels in feed and less overall phosphorus in poultry waste.
Swine Phytase	Phytase is an enzyme added to swine-feed that helps swine absorb phosphorus. The addition of phytase to swine feed allows for more efficient nutrient uptake by swine, which in turn allows decreased phosphorus levels in feed and less overall phosphorus in swine waste.
Precision Intensive Rotational Grazing	Practice utilizes more intensive forms of pasture management and grazing techniques to improve the quality and quantity of the forages grown on pastures and reduce the impact of animal travel lanes, animal concentration areas or other degraded areas of the upland pastures. PIRG can be applied to pastures intersected by streams or upland pastures outside of the degraded stream corridor (35 feet width from top of bank). This practice requires intensive management of livestock rotation, also known as Managed Intensive Grazing systems (MIG), that have very short rotation schedules.
Prescribed Grazing	Utilizes a range of pasture management and grazing techniques to improve the quality and quantity of the forages grown on pastures and reduce the impact of animal travel lanes, animal concentration areas or other degraded areas. PG can be applied to pastures intersected by streams or upland pastures outside of the degraded stream corridor (35 feet width from top of bank).
Stream Access Control w/ Fencing	Stream access control with fencing involves excluding a strip of land with fencing along the stream corridor to provide protection from livestock. The fenced areas may be planted with trees or grass, or left to natural plant succession, and can be of various widths. The implementation of stream fencing provides stream access control for livestock but does not necessarily exclude animals from entering the stream by incorporating limited and stabilized in-stream crossing or watering facilities.
Stream Restoration	A collection of site-specific engineering techniques used to stabilize an eroding streambank and channel. These are areas not associated with animal entry.
Tree Planting	Any tree planting, except those used to establish riparian forest buffers, targeting lands that are highly erodible or identified as critical resource areas.
Water Control Structures	Installing and managing boarded gate systems in agricultural land that contains surface drainage ditches.
Wetland Restoration	Activities to re-establish the natural hydraulic condition in a field that existed prior to the installation of subsurface or surface drainage. Projects may include restoration, creation and enhancement acreage.

Source: (Abt Associates/USEPA 2012)

Table 2. BMP Unit Costs

COST ($/unit/yr)							
BMP	**Unit**	**Delaware**	**Maryland**	**New York**	**Pennsylvania**	**Virginia**	**West Virginia**
Alternative Watering	$/ac/yr	$2,027.84	$2,027.84	$2,027.84	$2,027.84	$2,027.84	$2,027.84
Ammonia Emissions Reduction – Alum	$/AU/yr	$45.62	$44.54	$38.83	$38.83	$45.62	$45.08
Ammonia Emissions Reduction - Bio & Lagoon	$/AU/yr	$45.62	$44.54	$38.83	$38.83	$45.62	$45.08
AWMS - Livestock	$/AU/yr	$194.22	$194.22	$194.22	$194.22	$194.22	$194.22
AWMS - Poultry	$/AU/yr	$71.62	$71.62	$71.62	$71.62	$71.62	$71.62
Barnyard Runoff	$/ac/yr	$937.27	$508.80	$508.80	$508.80	$494.08	$501.44
Capture & Reuse	$/ac/yr	$1,067.83	$1,067.83	$1,067.83	$1,067.83	$1,067.83	$1,067.83
Carbon Sequestration	$/ac/yr	$20.11	$20.11	$20.11	$20.11	$20.11	$20.11
Commodity Cover Crops	$/ac/yr	$23.33	$66.67	$66.67	$66.67	$110.00	$110.00
Conservation Plan	$/ac/yr	$2.18	$2.18	$2.18	$2.18	$2.18	$2.18
Conservation Tillage	$/ac/yr	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Continuous No-Till	$/ac/yr	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Cover Crops	$/ac/yr	$52.00	$68.00	$74.67	$40.00	$109.38	$98.24
Cropland Irrigation Management	$/ac/yr	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Dairy Precision Feeding	$/AU/yr	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Decision Agriculture	$/ac/yr	$30.00	$33.44	$13.33	$13.33	$33.44	$33.44
Enhanced Nutrient Management	$/ac/yr	$9.10	$9.10	$9.10	$9.10	$9.10	$9.10
Forest Buffers	$/ac/yr	$98.11	$184.22	$202.59	$258.38	$86.17	$118.37
Grass Buffers	$/ac/yr	$105.88	$95.10	$76.69	$122.67	$75.05	$72.39
Horse Pasture Management	$/ac/yr	$26.32	$26.32	$22.47	$22.47	$26.32	$26.32
Land Retirement	$/ac/yr	$78.46	$73.37	$52.11	$63.29	$53.32	$46.52
Liquid/Poultry Manure Injection	$/ac/yr	$60.00	$60.00	$60.00	$60.00	$60.00	$60.00
Loafing Lot Management	$/ac/yr	$2,135.66	$2,135.66	$2,135.66	$2,135.66	$1,253.21	$1,694.44
Manure Transport - Inside CBWS	$/ton/yr	$27.53	$27.53	$27.53	$27.53	$27.53	$27.53

Manure Transport - Outside CBWS	$/ton/yr	$27.53	$27.53	$27.53	$27.53	$27.53	$27.53
Mortality Composters	$/AU/yr	$474.93	$474.93	$28.00	$87.57	$1,120.27	$216.95
Nutrient Management	$/ac/yr	$0.00	$6.34	$2.34	$0.00	$13.07	$10.50
Poultry Phytase	$/AU/yr	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Swine Phytase	$/AU/yr	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Precision Intensive Rotational Grazing	$/ac/yr	$53.33	$93.33	$93.33	$93.33	$84.29	$75.25
Prescribed Grazing	$/ac/yr	$33.33	$14.67	$13.33	$16.00	$29.49	$9.07
Stream Access Control w/ Fencing	$/ac/yr	$5,840.30	$5,840.30	$5,840.30	$5,840.30	$5,840.30	$5,840.30
Stream Restoration	$/ft/yr	$8.04	$8.04	$6.00	$6.00	$8.90	$9.75
Tree Planting	$/ac/yr	$79.30	$291.22	$184.75	$195.93	$111.40	$126.87
Water Control Structures	$/ac/yr	$19.52	$19.52	$19.52	$19.52	$19.52	$19.52
Wetland Restoration	$/ac/yr	$355.11	$350.02	$510.80	$392.02	$329.97	$323.17

Source: (Abt Associates/USEPA 2012) with discussed modifications

WIP Cost Estimates

We utilized the BMP costs to estimate the WIP costs by two different methods. The first method estimates the present value of the costs of achieving 2025 BMP implementation levels starting from a baseline year. We use two baseline years for these estimates: 2009 and 2011. Given that the TMDL was issued in 2011, the “with versus without” principle of benefit-cost analysis dictates using the 2011 baseline. However, USEPA has chosen to use a 2009 baseline and so we also report that for comparison purposes. This estimate considers only the costs of required BMP implementation through 2025. Because the WIPs do not indicate timing, and because timing affects the present value, an assumption about timing is required to estimate present values. While a variety of paths are plausible and could be considered, we assume implementation increases linearly until full BMP implementation is reached in 2025.

The second method estimates the annualized costs associated with full implementation of all WIP BMPs. This can be viewed as the annual cost of implementing all agricultural WIP BMPs at 2025 levels. For these estimates we use only the 2011 baseline. These methods are described in more detail below.

Agricultural WIP Implementation Costs - 2009/2011 through 2025: This cost estimate is for the incremental costs of new BMP implementation from a baseline year through 2025. For each BMP and jurisdiction, new implementation is calculated by subtracting the CBP baseline year implementation from 2025 implementation targets, as established in the WIPs for each appropriate jurisdiction. For each BMP, the baseline includes all implementation of that BMP credited in the CBM through that baseline year (either 2009 or 2011). 2025 implementation is drawn from the implementation amount for each BMP detailed in the WIPs for each jurisdiction.

Since the focus is on new implementation, costs associated with continued implementation and/or maintenance of existing BMPs are not included. In some cases, 2025 implementation levels were less than baseline implementation levels. In these cases, no new implementation was assumed to occur and the annual implementation level was set equal to zero. Future implementation could decrease as a result of moving toward enhanced versions of BMPs (i.e. moving from nutrient management to decision agriculture or enhanced nutrient management) or because of a reduction in agricultural acreage available due to land use changes.

Cost savings were not allowed in cases where implementation decreases. Decreasing implementation of one BMP through 2025 could open opportunities for increased implementation of other BMPs. In these cases, it could be argued that allowing cost savings (negative implementation) is appropriate. To truly represent a cost savings, elimination of one BMP has to lead to opportunities elsewhere. However, many of these BMPs have structural costs that cannot be recovered. Furthermore, it is impossible to know how and where substitution in implementation will occur. Since determining actual cost savings from decreasing implementation is essentially impossible, we adopted a default implementation of 0 acres instead of allowing negative implementation levels. This is consistent with our approach of choosing an upward bias in cost estimates when we have unavoidable ambiguities, and our general view of the cost estimates as an upper bound. In addition, net benefits for individual BMPs are not allowed. If net costs are believed to be zero or negative for a BMP (examples include tillage practices, cropland irrigation management, dairy precision feeding, and phytase), the unit cost for TMDL cost calculation purposes is set to $0. This creates a consistent upper bound on costs for these BMPs.

Our estimates are based on the recognition that implementation goals will not be reached at once, but that implementation will increase gradually from the baseline through 2025. We assume that implementation increases linearly between the baseline and 2025 for lack of a better assumption. Therefore, if the 2025 implementation target is 250 acres and the 2011 baseline is 110 acres, implementation totals would be 120 acres in 2012, 130 acres in 2013, and so on (i.e. 10 additional acres each year). Since we focus on new implementation, costs would reflect only those associated with the 10 additional acres each year.

Annual costs are calculated by multiplying annual implementation by unit cost estimates for each jurisdiction and BMP. Costs are discounted to the baseline year at an annual real discount rate of 7% per OMB requirements (OMB Circular No. A-94).

In addition to the reasons given above, one reason to view these estimates as an upper bound on the costs of implementing the agricultural portion of the TMDL through 2025 has to do with cost heterogeneity within each state. Cost estimates and implementation levels are only available at the state or Bay scale. However, one would expect costs to vary within each state. Failing to account for this heterogeneity will lead to less efficient implementation and higher TMDL cost estimates since it is impossible to determine least-cost implementation areas within each state.

Tables A.1 and A.2 in Appendix A summarize the discounted costs by BMP and jurisdiction for both the 2009 and 2011 baselines. The total cost utilizing the 2011 baseline is about $3.6 billon. The total cost utilizing the 2009 baseline is about $5.0 billion. Three BMPs (alternative watering, livestock waste management systems, and stream access control) together account for the majority of baseline costs: about 14.5% (2009) and 11.2% (2011) for alternative watering, about 20.7% (2009) and 26.2% (2011) for livestock waste management systems, and about 29.6% (2009) and 20.7% (2011) for stream access control.

The differences between the 2009 and 2011 baseline estimates are driven by differences in BMP implementation levels as provided by CBP. Approximately 76% of these differences are due to alternative watering and stream access control, with alternative watering accounting for approximately 23% of the difference and stream access control accounting for approximately 53% of the difference:

- Total cost difference: $5.0 billion (2009) - $3.6 billion (2011) = $1.4 billion
- Alternative Watering: $726 million (2009) - $403 million (2011) = $323 million
- Stream Access Control: $1.49 billion (2009) - $750 million (2011) = $740 million

Annualized Cost of Full WIP BMP Implementation of WIP: The total annual cost of installing the practices associated with the WIPs is also useful to calculate. This is a simple calculation of the annual cost of all new implementation called for in the WIPs beyond the 2011 baseline. In contrast with the estimated costs through 2025 described above, this cost concept reflects the long-term annual cost associated with installing and maintaining all of the practices called for in the WIPs. These costs are reflected in the undiscounted 2025 costs from the methodology above, as this is when full implementation is achieved. These costs are particularly useful as a source of comparison to estimated annual costs associated with a cost-effective implementation of practices.

It is important to note that this is a different cost concept than calculating the cost from the 2011 baseline year through 2025 detailed above, an estimated cost of $3.6 billion. That cost involved calculating the present value of gradually increasing BMP implementation from 2011 baseline levels to 2025 full implementation levels. It reflects the cost of achieving the TMDL over time from 2011 through 2025 only. The total annual cost estimate, in contrast, reflects the annual cost of full implementation of all BMPs at 2025 levels, a level of implementation not achieved until 2025 in the $3.6 billion cost estimate.

Annual cost estimates for installing and maintaining all new implementation beyond the 2011 baseline are presented in Table A.3 in Appendix A. These costs were calculated by subtracting 2011 baseline implementation from total 2025 implementation called for in the state WIPs for each BMP and multiplying this figure by the annual BMP cost. Any negative implementation is assigned a cost of $0. Utilizing this methodology, estimated costs for full implementation of the WIPs are about $900 million annually. Jurisdiction-specific annual WIP cost estimates are $19.4 million in Delaware, $83 million in Maryland, $71.2 million in New York, $378.3 million in Pennsylvania, $307.4 million in Virginia, and $44 million in West Virginia. Alternative watering (11.2%), livestock waste management systems (26.2%), and stream access control (20.7%) together account for the majority (58.1%) of total annual costs across the CBW. These high-cost practices prove less cost-effective than many others in the cost-effective implementation analysis discussed below.

Cost-Effective BMP Portfolios

A second objective of this cooperative agreement was to explore the potential for improving the cost-effectiveness of BMP implementation relative to the WIPs. Using the data available to this study, cost-savings may be achieved through some combination of overall BMP selection, emphasizing greater use of BMPs that are relatively more cost-effective in reducing nutrient and sediment pollution; and BMP targeting, emphasizing the placement of BMPs in locations that have greater impact on water quality. Accordingly, our analysis examines potential costs savings that can be achieved through attention to BMP cost-effectiveness in the selection of BMPs for land management units defined by the CBM, and in the targeting of land management units.

The basic data we need for this analysis are estimates of BMP cost-effectiveness. These are estimated using data on BMP cost and CBM parameters that indicate the effectiveness of

BMPs within and across land-river segments. Below we describe the cost-effectiveness of individual BMPs with respect to particular pollutants, marginal abatement cost curves for particular pollutants, and what we refer to as cost-effective BMP portfolios. The latter are the result of a multi-pollutant cost-effectiveness analysis.

BMP Pollution Reduction Efficiencies

In the CBM, most agricultural BMPs are assigned "reduction efficiencies" for nitrogen, phosphorus, and sediment according to the average pollutant-reducing capability of that BMP. This efficiency is the estimated fractional reduction in edge-of-segment loads for each pollutant. Edge-of-segment loads are the amount of each pollutant that reaches the boundary waters for that land-river segment.

Land use acres in the CBM are meant to model an average for that land use across the Bay. In other words, acres for each agricultural land use within land-river segments do not reflect the full heterogeneity found across the Bay for that land use, but represent average conditions for those acres. Similarly, for each BMP, identical reduction efficiencies are assumed to be the same for every land-river segment in the Bay as they are meant to capture representative reductions for that BMP on average. Reduction efficiencies do vary for some BMPs according to the land use they are applied to or according to hydrogeomorphic region. Other BMPs are accounted for by simulated land use changes or through a combination of a reduction efficiency and a land use change. Nutrient management is modeled explicitly with its own land uses in the Bay Model (USEPA 2010).

BMP Cost-Effectiveness

The BMP cost estimates discussed in the previous section, combined with reduction efficiencies from the CBM, can be used to estimate the cost-effectiveness of BMPs for the various pollutants in locations defined by the CBM. The cost-effectiveness estimates can be used with information on land use acreages and edge of segment loads by pollutant and land use to estimate the cost of installing BMPs within each land-river segment along with their associated nitrogen (N), phosphorous (P), and sediment (TSS) reductions. Since nutrient flows to the Bay vary across land-river segments according to distance and a number of land-based characteristics, we translated all load reductions into delivered load reductions to the Bay with the use of delivery factors for each pollutant and land-river segment. The CBP compiles "progress data" to monitor compliance with the TMDL. The progress data include acres and pollutant loadings by land use in each land-river segment. Consistent with our choice of 2011 as the baseline for analyzing the costs of the WIPs, we use the 2011 progress data as the baseline for our cost-effectiveness analysis, with the acres and pollutant loads simulated according to CBM runs including agricultural BMPs already installed within the 2011 progress data.

These data were utilized along with reduction efficiencies for each BMP and the USEPA BMP cost data discussed above to estimate load reductions and costs associated with a cost-effective implementation of BMPs. This involved using costs and load reductions to calculate a marginal abatement cost (MAC) for each BMP/land-river segment combination. Each BMP MAC represents the cost per pound of pollutant reduced to the Chesapeake Bay. More cost-effective BMPs are associated with a lower MAC and vice versa. However, since reduction efficiencies and loads differ for each of the three pollutants (N, P, and TSS), there is a different MAC in each BMP/land-river segment combination for each pollutant. This means that a BMP within a land-river segment could be very cost-effective for reducing nitrogen but not very cost-effective for reducing phosphorus, or vice versa. This complicates the cost-effective ranking of BMPs within land-river segments. This is further complicated by the fact that not all BMPs apply to all three pollutants.

BMPs Included in the Analysis

All agricultural BMPs for which we had complete data (BMP cost, reduction efficiency, and baseline land use) were included in our assessment of cost-effective implementation. The cost-effectiveness of a BMP for a pollutant is clearly contingent on BMP cost and the BMP reduction efficiency for the pollutant. Cost-effectiveness is also contingent on the load associated with the land uses to which a BMP is applied. Greater load reductions result from BMPs applied to land uses experiencing higher loadings. Distance from the Bay for the location in which the BMP is installed also plays a role, as BMPs installed in land-river segments with lower delivery factors (further distance from the Bay) have less of an impact on the Bay.

Some BMPs were excluded because they were unambiguously dominated by substitutes. Alternative watering is an important example. While figuring prominently in the WIPs, this BMP is clearly dominated by cheaper alternatives. The EPA estimates annual costs for alternative watering at $2028/acre/yr with reduction efficiencies of 5% for N, 8% for P, and 10% for TSS. Prescribed grazing can be applied to the same acres with costs ranging from $9/acre/yr to $33/acre/yr depending on the jurisdiction. Prescribed grazing also scores better than alternative watering in terms of reduction efficiencies (9-11% for N, 24% for P, and 30% for

TSS). Though they serve different purposes, the data imply that alternative watering is not cost-effective enough for nutrient reduction purposes in comparison to other BMPs, particularly since prescribed grazing is not among the most efficient BMPs in our analysis. Precision intensive rotational grazing (PIRG) is also excluded. PIRG and prescribed grazing have the same reduction efficiencies in the Bay Model, but costs for prescribed grazing are lower in all jurisdictions. Since both BMPs cannot be installed on the same acre, prescribed grazing will always be more cost efficient than PIRG.

The decision to exclude certain BMPs was done for the purposes of this exercise. For those BMPs excluded for cost-effectiveness reasons, it is important to note that they were excluded based on their costs and nutrient reduction performance according to the available data. This does not imply that these BMPs fail to provide valuable conservation benefits. Indeed, they do carry nutrient reduction benefits. Other BMPs were simply more efficient for the purposes of this exercise according to the data we utilized. We also do not consider other advantages that the excluded BMPs may have, such as non-water quality related benefits and local water quality benefits in the land-river segment where they are installed. This means that though our results are useful for increasing the economic efficiency of achieving TMDL target reductions, they do not provide a full or complete estimate of potential nutrient reductions or benefits from those reductions.

Our analysis includes two scenarios to reflect two basic approaches to reducing agricultural NPS. One is to implement pollution-reducing practices on working agricultural lands. The second is to convert crop lands to alternative uses, including lower intensity agricultural uses. Our first scenario is limited to BMPs installed on agricultural lands. Thus, agricultural BMPs that take agricultural land out of crop production such as buffers, land retirement, and wetland restoration are not included in the analysis for scenario one. The second scenario converts 25% of applicable land use acres in each land-river segment to either hay without nutrients, or forest, according to CBM rules. Land converted to hay without nutrients is classified as land retirement in the CBM while land converted to forest is classified as tree planting in the CBM (USEPA 2010). These land conversions are what we mean when we refer to land retirement in the remainder of the report. Conversion of lands to buffers or wetlands were not included as there were data limitations associated with accurately determining applicable acreages for conversion at the land-river segment scale for these BMPs.

We selected a land use scenario approach because it is straightforward and insightful. The economics of agricultural land use in the region generally, and as affected by the Bay TMDL, are complex and a significant research topic. The scope of this cooperative agreement did not include land use modeling.

Included BMPs along with their reduction efficiencies are listed in Table 3. Some reduction efficiencies are listed as ranges due to differences across land uses, hydrogeomorphic regions, or states. Land conversion BMPs such as conservation tillage, nutrient management, and stream access control are not assigned reduction efficiencies. For these BMPs, the CBP provided estimated reduction efficiencies. Reductions from land conversion to hay without nutrients or forest in scenario two were calculated directly as the difference between the pre- and post-BMP loading rates for each acre.

Table 3. Included BMPs and Reduction Efficiencies

BMP	Nitrogen Reduction Efficiency	Phosphorus Reduction Efficiency	Sediment Reduction Efficiency
Ammonia Emissions Reduction	60	N/A*	N/A
AWMS – Livestock	75	75	N/A
AWMS – Poultry	75	75	N/A
Barnyard Runoff	20	20	40
Capture & Reuse	75**	75**	N/A
Conservation Plan	3 - 8	5 - 15	8 - 25
Conservation Tillage	1.8 - 3.9***	3.7 - 7.5***	9.9 - 20.3***
Continuous No-Till	10 - 15	20 - 40	70
Cover Crops	34	0 - 15	0 - 20
Cropland Irrigation Management	4**	N/A	N/A
Dairy Precision Feeding	25	25	N/A
Enhanced Nutrient Management	7	N/A	N/A
Land Retirement	Varies by LR seg loading rates for pre- and post BMP land uses	Varies by LR seg loading rates for pre- and post BMP land uses	Varies by LR seg loading rates for pre- and post BMP land uses
Nutrient Management	4.5 - 9.9***	8.2 - 20.9***	N/A
Poultry Phytase	N/A	32%***	N/A
Swine Phytase	N/A	17% - 35%***	N/A
Prescribed Grazing	9 - 11	24	30
Stream Access Control w/ Fencing	26.1 - 53.8***	25.6 - 52.3***	9.2 - 63.4***
Water Control Structures	33	N/A	N/A

Source unless otherwise indicated: Brosch (2010)
*indicates the reduction efficiency is not applicable in the Phase 5.3.2 CBM, source: USEPA (2010)
**Source: Chesapeake Bay Program (2013)
***Source: Provided by Jeff Sweeney at CBP

Each BMP can be applied to a certain set of acceptable land uses according to the BMP's specific purpose. For example, prescribed grazing can only be applied to pasture and nutrient management pasture land uses, whereas conservation plans can be applied to most agricultural land uses. There are also rules within the Bay Model associated with which BMPs can be applied together on the same acres and remain eligible for loading reductions in the CBM. Those BMPs that can be applied together are considered multiplicative, because the installation of one decreases the nutrients available to be reduced by the others. In this way, the order of implementation matters for cost-effectiveness since the reduction efficiency for the first BMP applies to the entire load for that acre, while possible reductions for subsequent BMPs are decreased by the amount of prior BMP reductions. An example of multiplicative BMPs is cover crops applied to an acre that includes a conservation plan as well as enhanced nutrient management. Those BMPs that cannot be applied to the same acre are considered additive. Continuous no-till serves as a useful example. Acres under continuous no-till are not eligible for reductions from cover crops or nutrient management within the Bay Model. Thus, reductions from cover crops and continuous no-till are additive since they must be applied separately to different acres to receive credit within the Bay Model (USEPA 2010).

Partial Marginal Abatement Costs for Individual Pollutants

BMP cost-effectiveness by type and location is the basic data for assessments of economic efficiency in pollution control. One way to utilize such information to inform planning and to evaluate the merits of trading is to construct marginal abatement costs curves (MACs) that display the incremental cost of additional pollution control. Typically, MACs are constructed for individual pollutants that abstract from other contributing pollutants. In this section we construct partial agricultural MACs in recognition of the multi-pollutant environment of the Bay. Specifically, we consider the incremental costs of reducing specific pollutants (e.g. nitrogen), without consideration of others (e.g. sediment). Partial MAC curves are calculated for each pollutant by sorting each BMP/land-river segment MAC from low to high. Those practices in land-river segments that carry the lowest MAC are implemented first and so on until there are no practices left. These MAC curves serve as a guide to the most cost-effective BMP implementation. For one pollutant, a least-cost solution is found by finding the lowest cost BMP/land-river segment combination and installing that BMP in that parcel and so on as the MAC curve is traced out. Implementation is achieved once the CBM TMDL reduction target is met for that pollutant. There are many land-river segments with prohibitively expensive MAC practices that are not part of the least-cost solution.

Consistent with the CBM, all load reductions and costs are on an annual, long run average, basis. We assume BMPs are implemented on all available acres, with individual BMP reductions calculated based on a cost-effective order of implementation. Pollution abatement and costs are computed relative to a 2011 baseline. Taking account of baseline BMPs is necessary because the loading and acreage data we utilized were based on model runs that accounted for baseline BMPs. We accounted for baseline BMPs by calculating 2011 progress implementation for each BMP as a percentage of the total acreage available and basing cost and load reduction calculations only on those acres still available for implementation. Our method assumes a uniform implementation of baseline BMPs across land-river segments. This calculation does not apply to land conversion BMPs such as enhanced nutrient management, as any 2011 progress implementation was already accounted for in changes to nutrient management land uses.

BMPs were installed on all applicable acres within each land-river segment while adhering to the rules governing acceptable land uses for each BMP as well as those for multiplicative and additive BMPs. Furthermore, some BMPs such as water control structures and cropland irrigation management were only applicable in certain areas of the Bay. Total costs and load reductions, along with marginal abatement costs, were calculated for each land-river segment/BMP combination. This required calculating load reductions per acre for each applicable BMP land use, and then calculating total pounds reduced for each land use based on acres applied. Individual land use reductions were aggregated to yield a total reduction for the BMP/land-river segment combination. When subsequent BMPs were implemented, any prior load reductions per acre for each land use were accounted for. Marginal abatement costs for each land-river segment/BMP combination were calculated by dividing cost by delivered pounds reduced.

Within each land-river segment and for each pollutant, BMPs were installed in a cost-effective ordering according to their marginal abatement costs. The cost-effective ordering varied across land-river segments and pollutants. Therefore, implementation order sometimes had to be altered within land-river segments during the MAC calculation process so that BMPs were implemented from low MAC to high MAC. This resorting required a recalculation of load reductions, as each BMP installed reduces the load available to be reduced by subsequent BMPs. For example, if cover crops were implemented before water control structures in the initial ordering within a land-river segment, but the MAC for cover crops is greater than that for water control structures, a least-cost implementation order would switch the implementation order of these BMPs since these BMPs have some applicable land uses in common and are multiplicative. In this example, water control structures would be moved ahead of cover crops in this land-river segment and load reductions would be recalculated according to this new BMP ordering. The cost-effective BMP order varies across land-river segments because loads per acre vary across land-river segments for each land use, though land-river segments near to each other tend to have similar loads per acre.

Initial load reductions were calculated based on an individual pollutant basis – nitrogen, phosphorus, or sediment. In other words, total jurisdiction BMP costs and load reductions were calculated for each pollutant individually based on a cost-effective implementation order of BMPs for that pollutant alone. Marginal abatement costs vary for each pollutant due to varying acceptable land uses, loads, and reduction efficiencies. Therefore, the cost-effective ordering of BMPs within each land-river segment varies for N, P, and TSS. For example, based on CBP data, cover crops are a much more efficient BMP for nitrogen reduction compared to phosphorus reduction. Thus, cover crops tend to be implemented earlier for an N-based ordering of BMP implementation as compared to a P-based ordering. Total state-wide annual costs and load reductions were calculated for each BMP and for each individual pollutant by summing costs and reductions across all land-river segment/BMP combinations. Sorting all of the unique BMP/land-river segment combinations within a jurisdiction from low MAC to high MAC for N, P and TSS individually results in a cost-effective ordering of BMPs for that jurisdiction for each pollutant. Plotting MAC against total reductions results in a MAC curve.

Complete MAC curves for each jurisdiction and pollutant are presented in Figures B.1 – B.36 in Appendix B. MAC curves for scenario one (no land retirement) are presented in Figures B.1 – B.18 while MAC curves for scenario two (land retirement) are presented in Figures B.19 – B.36. Each curve in these figures is cut off at the MAC level where most reductions have been exhausted and the MAC curve is vertical or nearly vertical. Our rankings indicate some common BMP orderings across the land-river segments. The most cost-effective BMPS for all pollutants are conservation tillage practices, which we treat as having zero cost since they generally provide positive net private benefits (as contrasted to conventional tillage). Consistent with this assumption, a cost-effective plan will install tillage practices across land-river segments. The same is true of crop irrigation management for N (where applicable), dairy precision feeding for N and P, and phytase for P, as these are also zero-cost practices. Water control structures (where applicable) and conservation plans are among the most efficient non-animal feeding operation (AFO) practices. Animal feeding operation practices (outside of zero-cost practices) and barnyard runoff control are generally inefficient with high marginal abatement costs. Stream access control with fencing, a heavily represented practice in the WIPs, is highly inefficient according to our data and calculations. It accounts for a high percentage of total costs across all states in the WIPs, while providing relatively low pollutant reductions according to reduction data available. In cases where a cost-effective implementation yields reductions exceeding TMDL targets, removing high MAC practices to more exactly meet the targets nearly always eliminates stream access control as an implemented practice.

The variation in marginal abatement costs across BMPs is highest for phosphorus and lowest for sediment. This finding follows from the fact that both the pounds of sediment reaching the Chesapeake Bay and pounds reduced called for by the TMDL are highest for sediment and lowest for phosphorus.

In Figures 2 – 7 we show the percentage of our total load reductions that can be achieved at various MAC levels for each pollutant and jurisdiction. Figures 2 – 4 include results for scenario one (no land retirement) while Figures 5 – 7 include results for scenario two (land retirement of 25% of applicable acres). Total reductions are listed on the horizontal axis for each jurisdiction.

Without land retirement, the percentage of N reductions that can be achieved at a MAC less than $20/lb ranges from nearly 44 percent in West Virginia to over 94 percent in Delaware. Greater than 50 percent of reductions can be achieved at less than $20/lb in all jurisdictions except for West Virginia, a state with low N delivery factors that reduce cost effectiveness. Greater than 50 percent of reductions can be achieved at less than $10/lb in Delaware, Maryland, and Pennsylvania. Abatement cost levels are higher for phosphorus. Still, greater than 50 percent of phosphorus reductions can be achieved at a MAC less than $50/lb in all jurisdictions except for West Virginia. Once again, the highest reduction percentages are found in Delaware, Maryland, and Pennsylvania. Greater than 90 percent of TSS load reductions can be achieved at a cost of less than $0.50/lb in all jurisdictions except for West Virginia, where about 36 percent of reductions are achieved under $0.50/lb.

With land retirement, the reductions increase across jurisdictions and pollutants compared to the scenario without land retirement. In general, the percentage of N load reductions below each MAC threshold also increases across jurisdictions. Greater than 50 percent of reductions can be achieved at less than $20/lb in all jurisdictions. Though the absolute value of phosphorus reductions increases with land retirement, the percentage of reductions under each MAC threshold decreases, in general. This is because land retirement reduces the scale of implementation of some comparatively low P MAC practices. The percentage of load reductions below each TSS MAC threshold remains high with land retirement.

Figure 2.

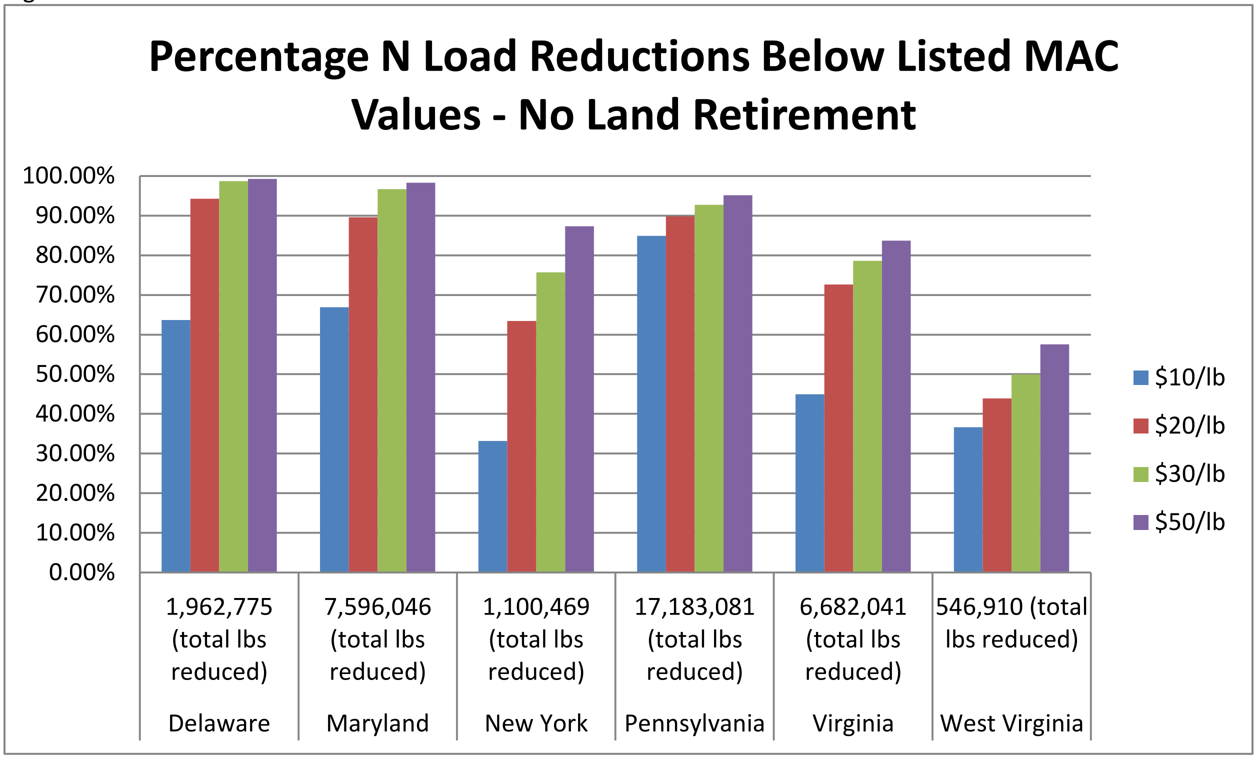


Figure 3.

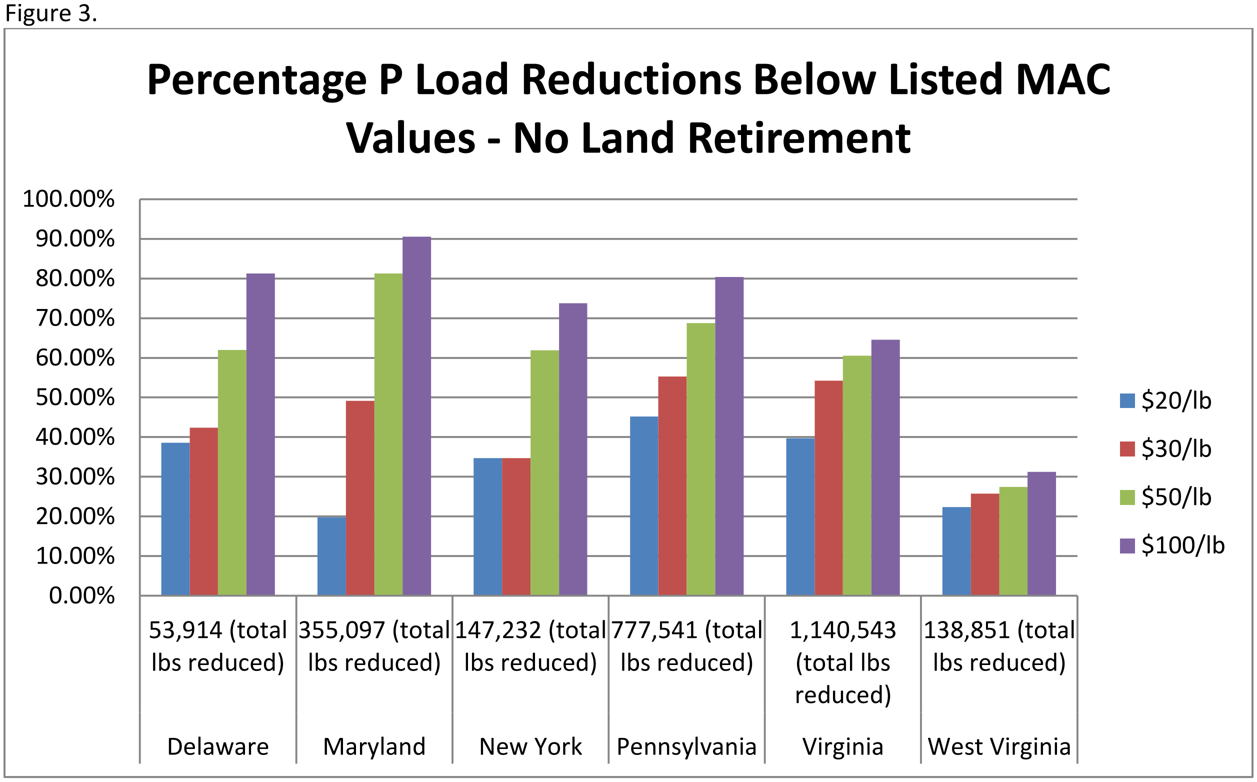


Figure 4.

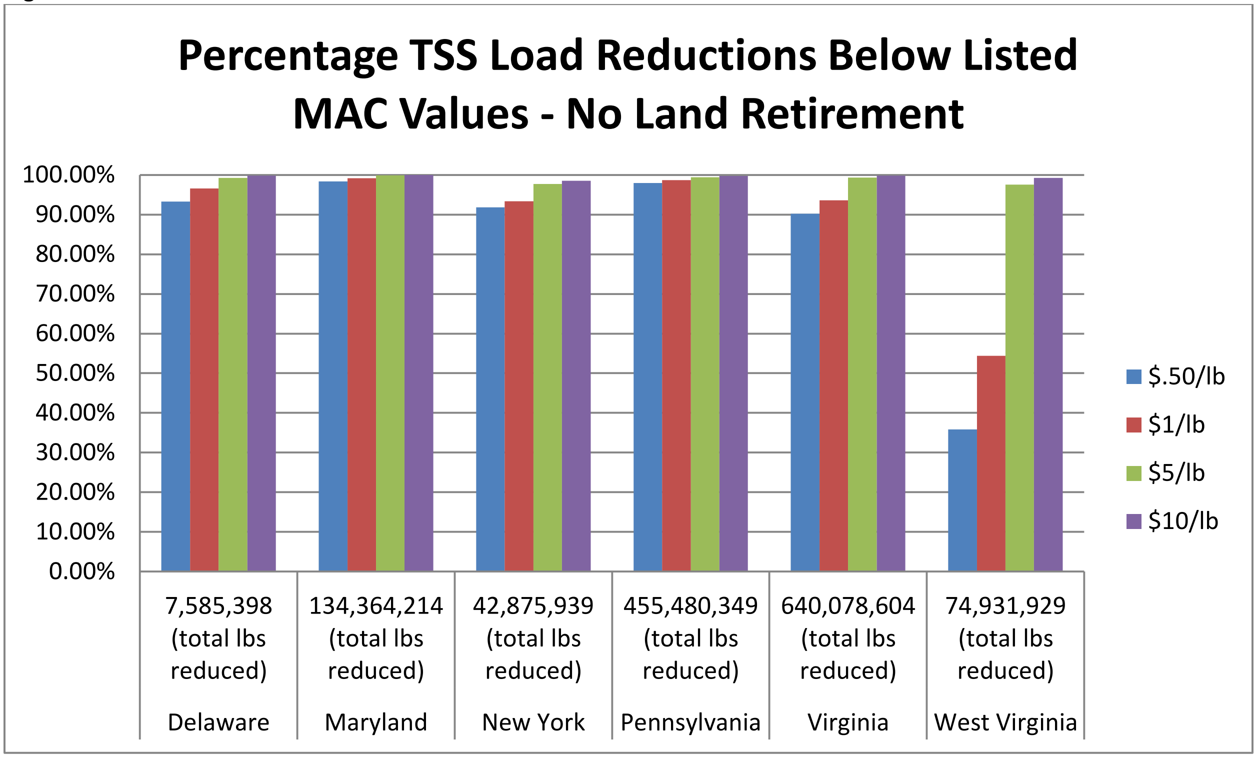


Figure 5.

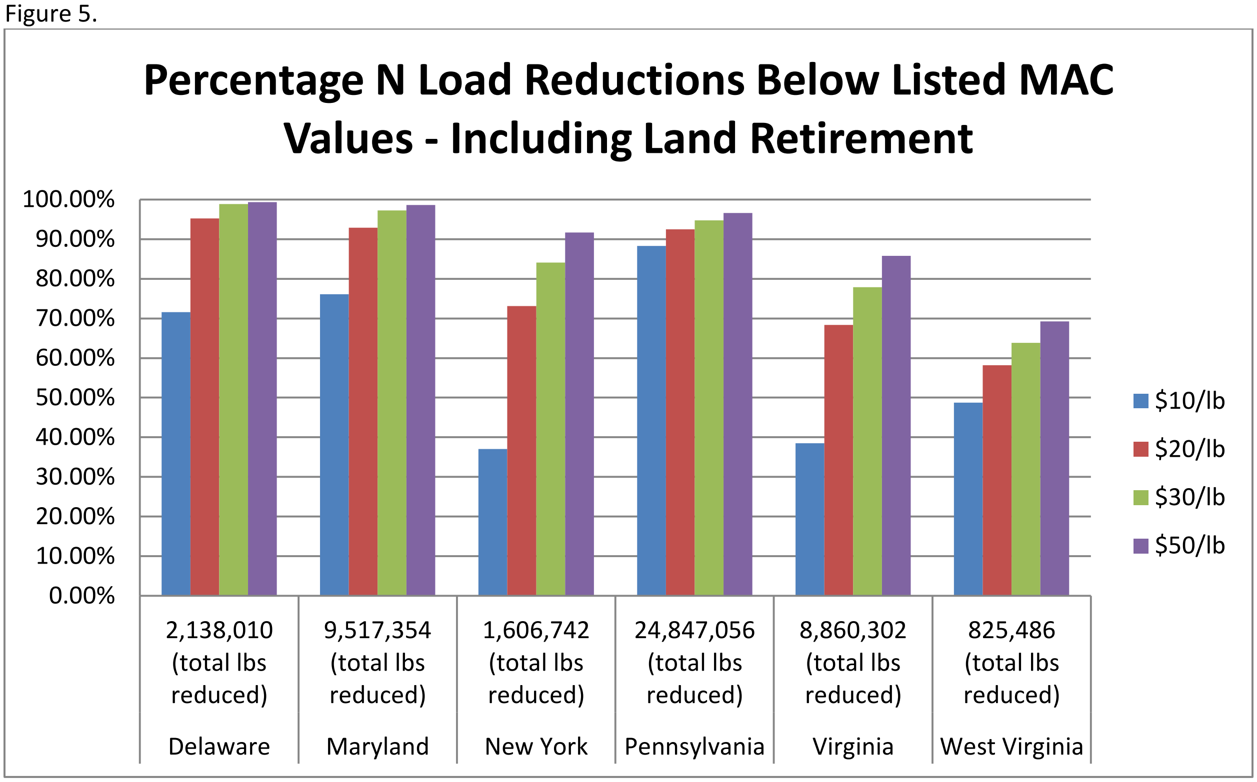


Figure 6.

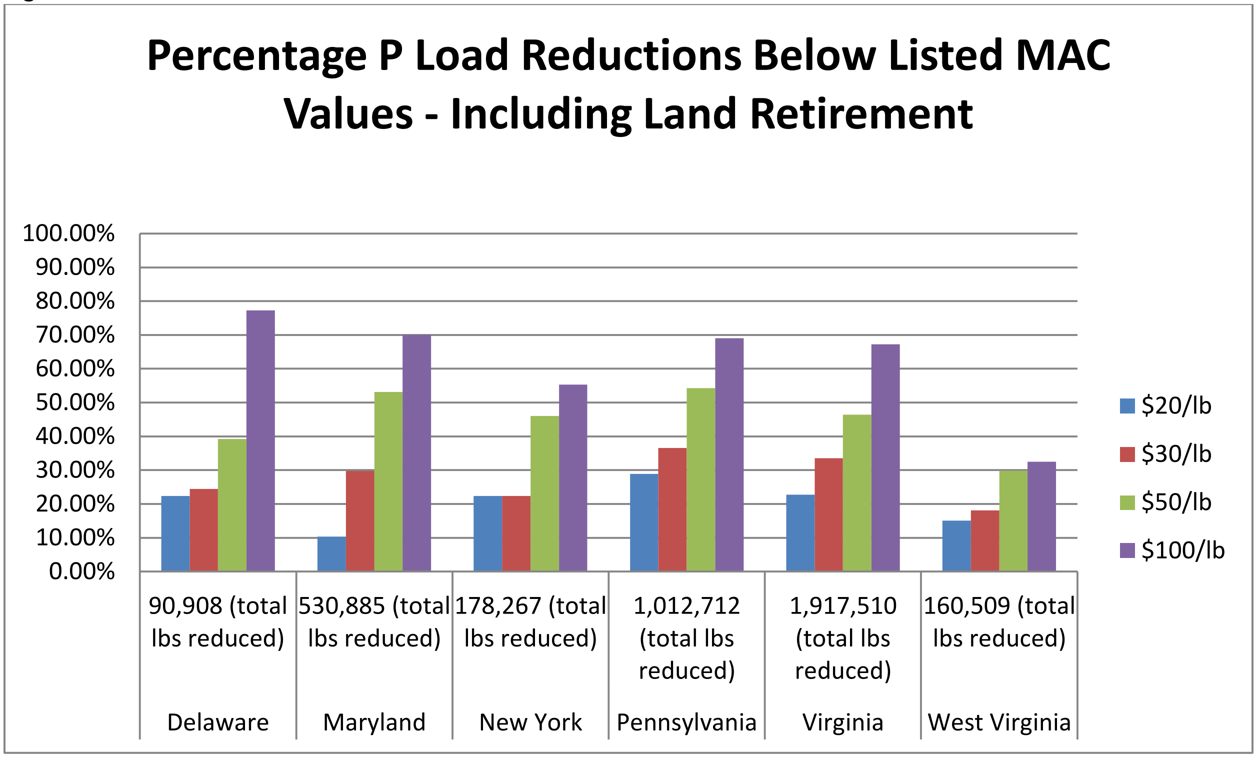
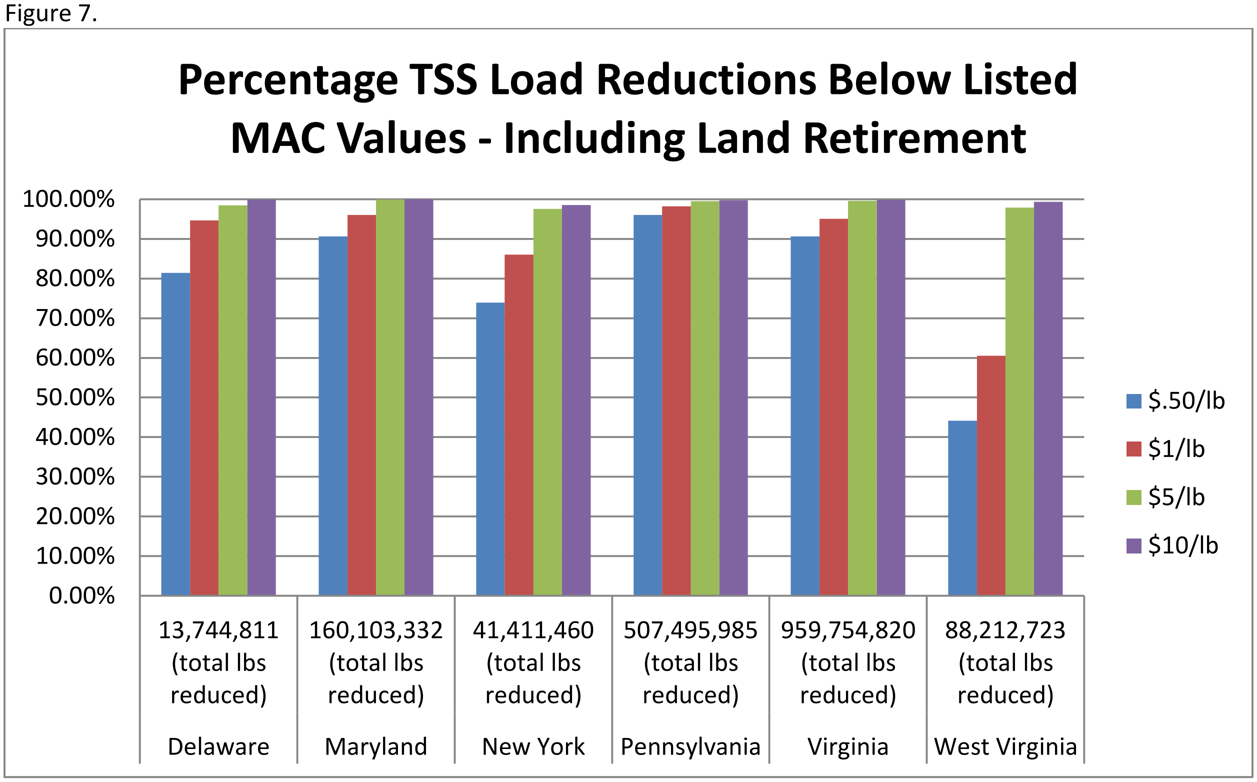


Figure 7.



Cost Effective Portfolios

The partial MACs are useful for considering the efficient management and trading of individual pollutants in abstract from others. However, overall efficiency requires cost-minimization in a multi-pollutant environment. Our cost-effective portfolios address this issue. Ultimately, total reductions in each jurisdiction must satisfy three TMDL reduction targets, one for each pollutant. Finding low cost solutions in each jurisdiction for achieving pollution reduction targets is complicated by the fact that the suite of BMPs implemented must satisfy N, P, and TSS load reduction targets. The process would be straightforward if there was only one pollutant. BMP/land-river segment combinations could be implemented based on MAC for that pollutant in each jurisdiction, from low to high, with practices implemented until required reductions are achieved for that pollutant. This process does not work for achieving N, P and TSS load reductions simultaneously because the cost-effective order of BMP implementation varies for each pollutant. As described above, load reductions differ for different BMP implementation orderings since BMPs implemented first reduce reductions available for subsequent BMPs implemented. A common ordering is necessary for accurate BMP load reduction calculations.

Thus, it was necessary to recalculate costs and load reductions in the following ways: (a) N and TSS costs and load reductions were recalculated based on a cost-effective BMP ordering for P, and (b) P and TSS costs and load reductions were recalculated based on a cost-effective BMP ordering for N. There were fewer TSS BMPs, so it was not necessary to recalculate N and P loads according to a TSS target. A TSS target resulted in a BMP ordering nearly identical to a P-based BMP ordering. With multiple pollutant targets, these recalculations were useful in allowing us to see which ordering of BMPs yielded a lower cost solution for achieving all three TMDL pollutant reduction targets simultaneously.

For this analysis, we compared our total calculated reductions for each pollutant and state to CBM TMDL load reduction targets for unregulated (non-CAFO) agriculture for the corresponding pollutant and state from 2011 to 2025. TMDL load reduction targets were calculated for each pollutant and jurisdiction by subtracting 2011 baseline loads from 2025 load allocations for unregulated agriculture. CBM TMDL load reduction targets for each pollutant were provided by CBP. In most cases, our calculated reductions exceeded CBM TMDL load reduction targets. This allowed for significant cost savings across all jurisdictions as high MAC BMPs could be eliminated.

The methodology for calculating the cost associated with achieving all CBM TMDL pollution reduction targets in a jurisdiction for each cost-effective ordering was as follows. For an N-based ordering in each jurisdiction, BMP/land-river segment combinations were implemented in order starting with the lowest N MAC onward. All N reductions were summed along with accompanying P and TSS reductions for each BMP/land-river segment combination implemented. Thus, implementation traces out the N MAC curve for each jurisdiction. Implementation was stopped once CBM TMDL load reduction targets were met for all three pollutants. A similar process was repeated for each P MAC curve. Some additional work was required when practices were implemented based on a P MAC curve because there were several N-only practices (water control structures, enhanced nutrient management, biofilters) that were sometimes necessary to implement in order to reach the CBM TMDL N load reduction target. Practices were implemented from low P MAC to high P MAC until the P and

TSS load reduction targets were met along with accompanying N reductions. If the N load reduction target was not yet met, N-only BMPs were then installed from low MAC to high MAC until the N load reduction target was met.

This process results in implementing only the most efficient (lowest MAC) BMP/land-river segment combinations necessary to meet all load reduction targets for the pollutant that the BMP ordering is based on. These solutions were compared to see if an N- or P-based ordering produced a lower cost solution, with the lowest cost solution chosen. We utilized this process for both scenario one (no land retirement) and scenario two (25% land retirement). Since scenario two converted 25% of the applicable land use acres in each land-river segment to either hay without nutrients or forest, the acreage available for other BMPs and their accompanying reductions were decreased by 25% for converted acres. However, both hay without nutrients and forest are low loading land uses, resulting in an increase in load reductions for all pollutants and jurisdictions under scenario two as compared to scenario one.

Our results indicate significant cost savings can result through implementation mechanisms or plans that encourage selection of BMPs and spatial targeting according to cost-effectiveness, as compared to the costs of installing the BMPs associated with the state WIPs. Results are included for both scenario one and scenario two.

Under scenario one (no land retirement), large cost savings are achieved in Delaware, Maryland, New York, and West Virginia upon exclusion of high MAC BMPs. In this scenario, Pennsylvania and Virginia are the only states where reductions from our suite of BMPs do not reach CBM TMDL load reduction targets. This has the effect of increasing implementation costs in these states because all practices, even prohibitively expensive ones, are required. In

Pennsylvania, our load reductions meet about 72% of the state's N target, about 98% of its P target, and about 97.5% of its TSS target. Results for Pennsylvania are included because costs associated with our solution are less than the annual costs of implementing Pennsylvania's WIP BMPs despite noncompliance with the TMDL. In Virginia, the N load reduction target is met, but our load reductions meet only about 62% of the state's P target and about 94.5% of its TSS target. Costs associated with full implementation of our suite of BMPs exceed those for implementing Virginia's WIP. Thus, our scenario one solution is not cost-effective and Virginia's results are not listed. Land retirement is necessary to achieve all TMDL load reduction targets in Pennsylvania and Virginia.

Our suite of BMPs does not include every WIP BMP. As discussed above, some BMPs are eliminated due to data limitations or the desire to focus on BMPs applied to productive agricultural lands. Alternative routes to reaching CBM TMDL load reduction targets could include interim BMPs or other BMPs not included in this report such as manure transport. For example, Pennsylvania's WIP calls for use of various manure treatment technologies for which complete data are not currently available. Regardless, scenario one results imply that significant cost savings can be achieved across the CBW by tailoring both the type and location of BMP implementation. Adding scenario two strengthens our analysis by including a percentage of land retirement in addition to the scenario one BMPs.

Scenario two converts 25% of applicable acres in each land-river segment to either hay without nutrients or forest. This has the effect of reducing the available acres for scenario one BMPs by 25% for those acres retired. Land retirement practices are relatively cost-efficient in comparison to some agricultural practices that involve keeping land in production. Conversion to hay without nutrients is the more cost-effective solution for reducing nutrient loads in every state except Virginia. In Virginia, conversion of land to forest is necessary in order to achieve its TSS load reduction target. Including land retirement increases the load reductions for all three pollutants in each jurisdiction. All CBM TMDL load reduction targets are met in this scenario with large cost savings in every jurisdiction as compared to WIP costs.

In Delaware, Virginia, and West Virginia, a P-based ordering yields the lowest cost solution while an N-based ordering yields the lowest cost solution for Maryland, New York, and Pennsylvania. Within each jurisdiction, BMP/land-river segment practice combinations are implemented in ascending MAC order until all TMDL load reduction targets are met, if possible.

Tables 4 and 5 below summarize WIP and cost-effective BMP portfolio costs for scenarios one and two, respectively. Tables A.4 – A.14 in Appendix A list full results of our cost-effectiveness analysis for each jurisdiction and scenario. Tables A.4 – A.8 list jurisdiction-specific BMP costs and reductions associated with the cost-effective BMP portfolio for scenario one. Virginia is not included because costs associated with our suite of practices exceeded WIP costs. Tables A.9 – A.14 list jurisdiction-specific BMP costs and reductions associated with the cost-effective BMP portfolio for scenario two. The tables are laid out in the following way. Costs and the accompanying load reductions associated with each jurisdiction's cost-effective BMP portfolio are broken down by BMP, followed by total costs and reductions. In the process of implementing the lowest MAC practices until all CBM TMDL load reduction targets are achieved, some BMPs are completely eliminated in our cost-effective portfolios due to high MAC. For those BMPs, their MAC in every LR segment is higher than the MAC threshold where all TMDL targets are achieved. The last two rows, highlighted in blue, list data for the WIPs, including estimated annual costs for installing all WIP practices along with CBM TMDL load reduction targets for N, P, and TSS. This illustrates our estimated cost savings as compared to annual WIP costs. It also shows that our solutions meet TMDL load reduction targets in most cases. The load reduction targets are the most up-to-date figures that were available from the CBP. Surprisingly, CBP data resulted in some sediment load reduction targets being negative.

Figures B.37 – B.47 in Appendix B summarize the distribution of costs for our cost-effective portfolios (CEP) for each jurisdiction and scenario. Costs are broken down by BMP. Zero-cost BMPs such as tillage practices, nutrient management (in Delaware and Pennsylvania according to USEPA/Abt unit cost estimates), cropland irrigation management (in Delaware and Maryland), and animal feeding practices are implemented to their fullest extent though they are not included in the figures due to their zero cost nature. Scenario one and scenario two results for each jurisdiction are presented adjacent to each other for comparison. In all cases, a portion or the entirety of the implementation of certain scenario one BMPs is replaced by land retirement in scenario two due to its cost-effectiveness as compared to some scenario one BMPs.

Scenario one results in Bay-wide cost savings of 30% as compared to total annual WIP costs. Bay-wide savings doubles to 60% upon including land retirement in scenario two. In Delaware, the estimated annual WIP cost is about $19 million. In comparison, the cost-effective portfolios yield costs of about $4 million (~80% savings) and $3.5 million (~82% savings) for scenarios one and two, respectively. Implementing least-cost practices illustrates the relatively high MAC associated with biofilters, livestock waste management systems, cover crops, and prescribed grazing in Delaware, as these practices are completely eliminated.

In Maryland, the estimated annual WIP cost is about $83 million. The cost-effective BMP portfolios yield costs of about $12.8 million (~85% savings) and $12.9 million (~84% savings) for scenarios one and two, respectively. Results imply that BMPs applied to productive agricultural land are preferable to land conversion in Maryland as scenario one yields greater cost savings. Many of the same practices are excluded in Maryland as in Delaware. These practices include biofilters, animal waste management systems, and stream access control.

Annual WIP costs in New York are approximately $71.2 million. The cost-effective BMP portfolios yield costs of about $51.8 million (~27% savings) and $10.1 million (~86% savings) for scenarios one and two, respectively. In this case, including land retirement increases cost savings substantially. This is because our complete scenario one N load reductions only slightly exceed New York's TMDL N load reduction target, allowing the elimination of fewer high MAC BMPs. Including land retirement results in more comparatively low cost N load reductions. As a result, high MAC practices such as biofilters, animal waste management systems, and stream access control are eliminated in scenario two, along with their associated costs.

In Pennsylvania, we estimate that WIP costs are approximately $378.3 million annually. Costs associated with scenario one are about $241.3 million, a 36% savings. However, TMDL load reduction targets are not met under this scenario. All targets are met when land retirement is included, along with significant cost savings as a result of the removal of high MAC BMPs. Scenario two costs are about $101.6 million, a savings of approximately 73% as compared to WIP cost estimates.

Virginia's WIP costs are estimated at $307.4 million annually. Scenario one results are not included as our estimated costs exceed Virginia's estimated WIP costs. This is the result of the implementation of prohibitively expensive practices. However, the cost-effective BMP portfolio for scenario two yields estimated costs of $223.6 million, a cost savings of approximately 27% as compared to WIP costs.

Annual WIP costs are approximately $44 million in West Virginia. In comparison, the cost-effective BMP portfolios yield costs of about $16.8 million (~62% savings) and $6 million (~86% savings) for scenarios one and two, respectively. Once again, practices such as biofilters and animal waste management systems are excluded due to the comparatively high marginal abatement costs associated with these practices.

Table 4. Scenario One Results Summary – WIP vs. Cost-Effective BMP Portfolio

Scenario One – No land retirement	WIP	Cost-Effective Portfolio	Saving
Delaware	$19.4m	$4m	80%
Maryland	$83m	$12.8m	85%
New York	$71.2m	$51.8m	27%
Pennsylvania	$378.3m	$241.3m	36% **
Virginia	$307.4m	NF (P)	NF (P)
West Virginia	$44m	$16.8m	62%
Total	$903m	$634.1	30%

**Pennsylvania met ~72% of its N Target, ~98% of its P target, and ~97.5% of its TSS target

Table 5. Scenario Two Results Summary – WIP vs. Cost-Effective BMP Portfolio

Scenario Two – Land Retirement	WIP	Cost-Effective Portfolio	Saving
Delaware	$19.4m	$3.5m	82%
Maryland	$83m	$12.9m	84%
New York	$71.2m	$10.1m	86%
Pennsylvania	$378.3m	$101.6m	73%
Virginia	$307.4m	$223.6m	27%
West Virginia	$44m	$6m	86%
Total	$903m	$357.7	60%

Nutrient Trading

Trading programs have been developed by Maryland, Pennsylvania, and Virginia, and are under development in West Virginia. These programs govern trading within the states' boundaries. The Chesapeake Bay Program is working on trading rules for trading across state boundaries. In our analysis we focus on potential economic gains from trading nitrogen and phosphorous. Potential gains from trade exist when there is sufficient heterogeneity in the marginal cost of abatement between pollution sources. When this is the case, overall pollution abatement costs can be reduced by reallocating pollution reductions from relatively high cost sources to relatively low cost sources. Whether gains from trade can be realized depends on trading rules, trading institutions, and the choices of eligible polluters. Trading rules define such things as who may trade, the conditions under which they may trade, what can be traded, and trading ratios. Trading institutions are the formal and informal mechanisms providing traders with information about the market, and organizing, executing, and enforcing contracts. Realizing the economic potential of trading requires rules and institutions that do not create unnecessary legal or economic barriers to beneficial trades, and that can facilitate efficient trading activity (Shortle 2013). In this analysis we do not evaluate trading rules or institutions, but instead focus on potential gains from trading.

The existence of multiple pollutants that are economically and technologically managed jointly complicates both the calculation of a cost-effective solution for achieving load reduction targets and analyzing the potential benefits from trading. Our trading analysis is based on the lowest cost solution for BMP implementation discussed in the cost-effectiveness analysis above. That is, load reductions and marginal abatement costs for each pollutant are derived from a BMP ordering based on the pollutant that yields the lowest cost solution within each jurisdiction. A P-based ordering of BMPs produces the lowest cost solution for Delaware, Virginia, and West Virginia. An N-based ordering produces the lowest cost solution for Maryland, New York, and Pennsylvania. We used load reductions and MAC data for each BMP/land-river segment combination to develop MAC curves for nitrogen and phosphorus for various trading baselines. Our analysis includes both scenarios one and two. Since the relevant MAC curve for each baseline and scenario indicates tradable N and P credits for that baseline/scenario combination, these MAC curves can be viewed as credit supply curves.

The relevant credit supply curve for trading will vary by the baseline chosen. Baseline compliance indicates requirements for nonpoint sources in order to be eligible to generate credits for trading. Baseline compliance can take the form of a minimum set of BMPs that must be adopted. For example, Virginia's nutrient trading program requires the adoption of five BMPs in order to be eligible to trade: soil conservation plan, nutrient management plan, cereal cover crops, exclusionary livestock fencing, and vegetative buffers. In Maryland, nonpoint sources are required to meet their portion of Maryland's nutrient reduction goal, defined by per-acre annual loading rates for nitrogen and phosphorus (Branosky et al. 2011).

We develop credit supply curves for nitrogen and phosphorus based on two main baseline scenarios. The first is the least restrictive option of no baseline compliance. This means that all future reductions are eligible for credit generation within a nutrient trading program. The second baseline is a jurisdiction-wide baseline requiring each jurisdiction to comply with TMDL load reduction targets for each pollutant before being eligible to generate credits. In other words, agriculture load reduction targets must be met by agricultural BMPs within each jurisdiction, with the only tradable credits being those over and above compliance with the TMDL load reduction targets. We also used a third baseline scenario for Virginia since their nutrient trading program identifies specific BMPs that must be implemented to participate in trading. These BMPs are conservation plans, nutrient management, cover crops, exclusionary livestock fencing, and buffers. Our analysis includes all practices except buffers. However, we can still identify potentially tradable loads above and beyond the implementation of these baseline BMPs, assuming buffers have also been installed. Any baseline will reduce the number of credits available for trading as compared to a no baseline scenario. As a result, available credits after baseline compliance are more expensive and there are less of them.

Table 6 details the tradable pounds of nitrogen for each jurisdiction under each baseline for scenarios one and two. Jurisdiction-specific credit supply curves associated with each baseline and scenario can be found in Figures 8 – 13. Results illustrate that requiring jurisdictions to meet their TMDL load allocation before generating credits simultaneously reduces the quantity of credits available while increasing their price. For both scenarios, the total number of credits available is less at every MAC level under the TMDL load allocation baseline. This is because the lowest-cost credits are devoted to achieving the TMDL load allocation under this baseline. The BMP baseline in Virginia yields many tradable load reductions. However, requiring a minimum set of BMPs for compliance ignores the heterogeneity in the cost-effectiveness of BMPs across both space and BMP type. It requires the implementation of some very cost-ineffective BMPs, including stream access control. According to the CBP data, this practice is consistently one of the most cost-inefficient practices.

In comparing scenario one results with scenario two, we see a general increase in the total number of tradable credits when land retirement is included, for both baselines. Without a baseline, the number of tradable credits increases substantially at every price level across jurisdictions except at the most stringent MAC levels of $5/lb and $2/lb. Including land retirement reduces the number of tradable credits below $2/lb in every jurisdiction except Pennsylvania. This is because including land conversion reduces the scale of implementation of some low cost BMPs such as tillage practices.

With no baseline, Maryland, Pennsylvania, and Virginia are the largest sources of low cost N load reductions. Pennsylvania has far and away the largest supply of credits without a baseline, though most of these credits are devoted to achieving its load reduction target as it has much fewer tradable credits under the TMDL target baseline. Delaware and Maryland have the largest numbers of tradable credits under the TMDL target baseline across both scenarios. Virginia's supply of tradable credits increases substantially under the TMDL target scenario upon including land retirement.

The potential cost reductions associated with nutrient trading will vary not only by the baseline chosen, but also by the extent to which trading is allowed. Larger cost reductions can be realized if inter-state trading is allowed. EPA has suggested that 9 million pounds of nitrogen and 200,000 pounds of phosphorus can safely be traded across major basins without negatively impacting local water quality (Van Houtven et al. 2012). With no baseline, this 9 million pound nitrogen threshold is reached at a cost of less than $5/lb with about 17.5 million and 23.9 million tradable pounds of N under scenarios one and two, respectively. Pennsylvania alone has more than 9 million pounds of tradable N credits at a MAC less than $5/lb under both scenarios. If the TMDL target baseline is adopted, the number of credits available drops significantly and the price increases under both scenarios. For scenario one, there are approximately 5.5 million tradable pounds of N available in total, with 4.3 million pounds available at a MAC less than $20/lb and 2 million pounds at a MAC less than $10/lb. Scenario two yields 9 million pounds of tradable credits at a price of approximately $30/lb, with 8.3 million pounds available at a MAC less than $20/lb and 5.6 million pounds at a MAC less than $10/lb.

Table 6 – Summary of Tradable Nitrogen Loads at Various MAC Thresholds: Scenario One and Scenario Two

Nitrogen Tradable Pounds	Scenario One (No Land Retirement)			Scenario Two (Land Retirement)		
DELAWARE	**No Baseline**	**TMDL Target Baseline**		**No Baseline**	**TMDL Target Baseline**	
Total Tradable Pounds	1,962,775	1,080,577		2,138,010	1,254,927	
Tradable lbs Below $20/lb	1,850,705	1,005,073		2,036,326	1,153,243	
Tradable lbs Below $10/lb	1,249,058	414,996		1,530,866	658,499	
Tradable lbs Below $5/lb	780,249	0		607,008	0	
Tradable lbs Below $2/lb	195,451	0		166,088	0	
MARYLAND	**No Baseline**	**TMDL Target Baseline**		**No Baseline**	**TMDL Target Baseline**	
Total Tradable Pounds	7,572,054	4,001,701		9,496,823	5,932,498	
Tradable lbs Below $20/lb	6,782,083	3,211,730		8,820,297	5,255,971	
Tradable lbs Below $10/lb	5,068,816	1,498,463		7,231,069	3,666,743	
Tradable lbs Below $5/lb	2,467,251	0		2,665,974	0	
Tradable lbs Below $2/lb	821,557	0		623,373	0	
NEW YORK	**No Baseline**	**TMDL Target Baseline**		**No Baseline**	**TMDL Target Baseline**	
Total Tradable Pounds	1,100,066	4,364		1,606,436	500,671	
Tradable lbs Below $20/lb	699,483	0		1,182,353	76,588	
Tradable lbs Below $10/lb	376,383	0		607,442	206	
Tradable lbs Below $5/lb	339,819	0		284,147	0	
Tradable lbs Below $2/lb	339,819	0		262,337	0	
PENNSYLVANIA	**No Baseline**	**TMDL Target Baseline**		**No Baseline**	**TMDL Target Baseline**	
Total Tradable Pounds	17,183,081	0		24,875,547	1,122,363	
Tradable lbs Below $20/lb	15,433,651	0		22,998,600	0	
Tradable lbs Below $10/lb	14,589,693	0		21,972,621	0	
Tradable lbs Below $5/lb	12,526,424	0		19,029,458	0	
Tradable lbs Below $2/lb	3,876,545	0		4,996,514	0	
WEST VIRGINIA	**No Baseline**	**TMDL Target Baseline**		**No Baseline**	**TMDL Target Baseline**	
Total Tradable Pounds	546,910	369,539		825,486	648,442	
Tradable lbs Below $20/lb	239,930	104,155		480,270	366,789	
Tradable lbs Below $10/lb	200,630	70,832		402,656	320,110	
Tradable lbs Below $5/lb	109,907	0		232,071	154,183	
Tradable lbs Below $2/lb	101,662	0		76,856	0	
VIRGINIA	**No Baseline**	**TMDL Target Baseline**	**BMP Baseline**	**No Baseline**	**TMDL Target Baseline**	**BMP Baseline**
Total Tradable Pounds	6,682,041	9,723	3,734,942	8,860,302	2,180,265	6,595,835
Tradable lbs Below $20/lb	4,853,313	0	2,765,112	6,054,264	1,433,014	4,487,209
Tradable lbs Below $10/lb	3,005,917	0	2,469,431	3,409,123	927,991	3,005,984
Tradable lbs Below $5/lb	1,372,487	0	1,266,573	1,068,210	51,096	988,592
Tradable lbs Below $2/lb	941,872	0	941,872	724,338	0	724,338

Figure 8.

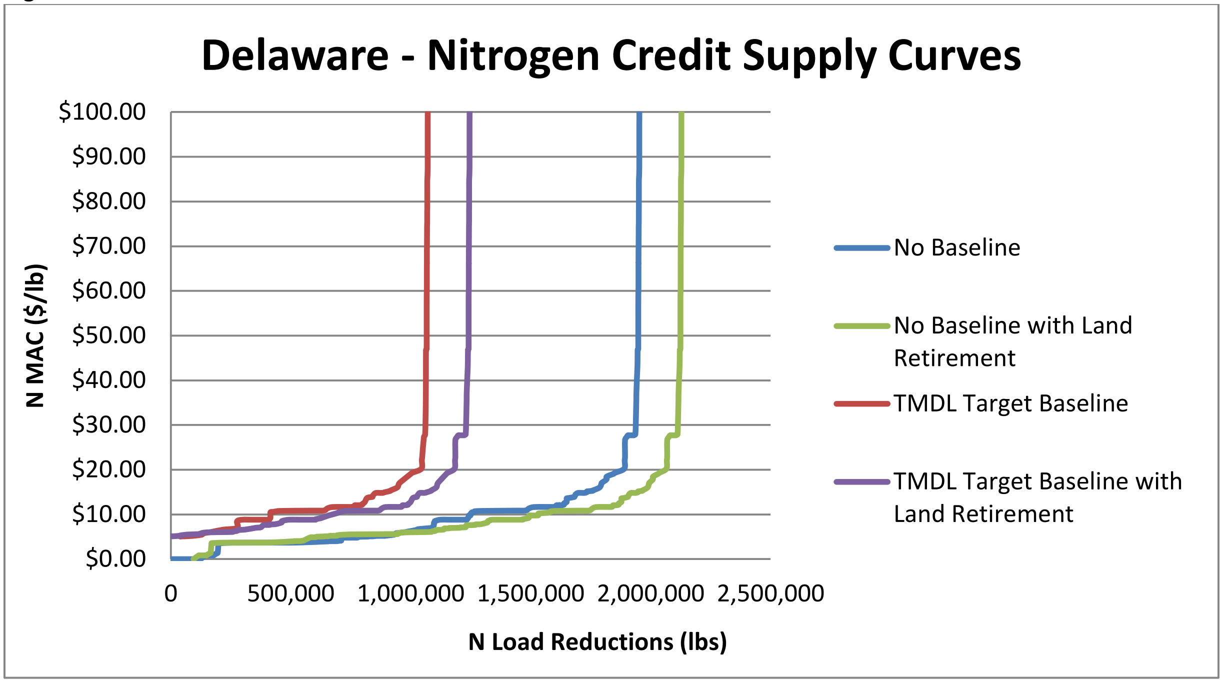


Figure 9.

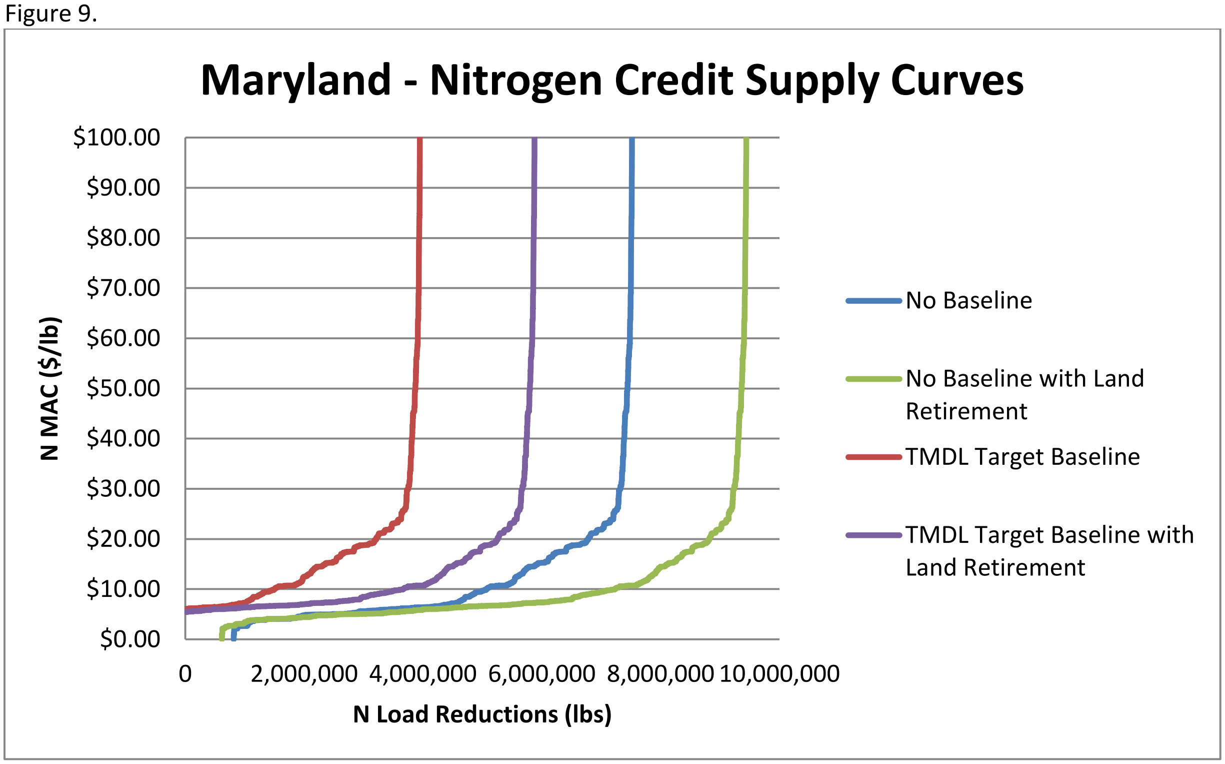
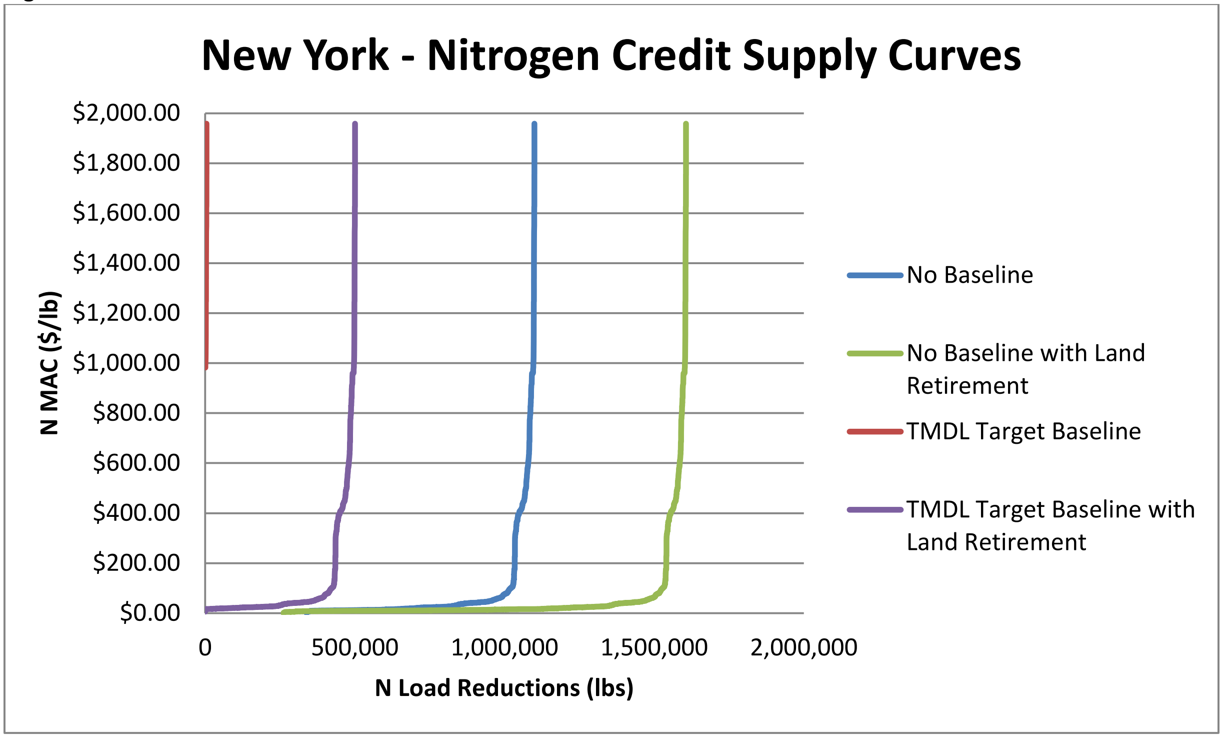


Figure 10.



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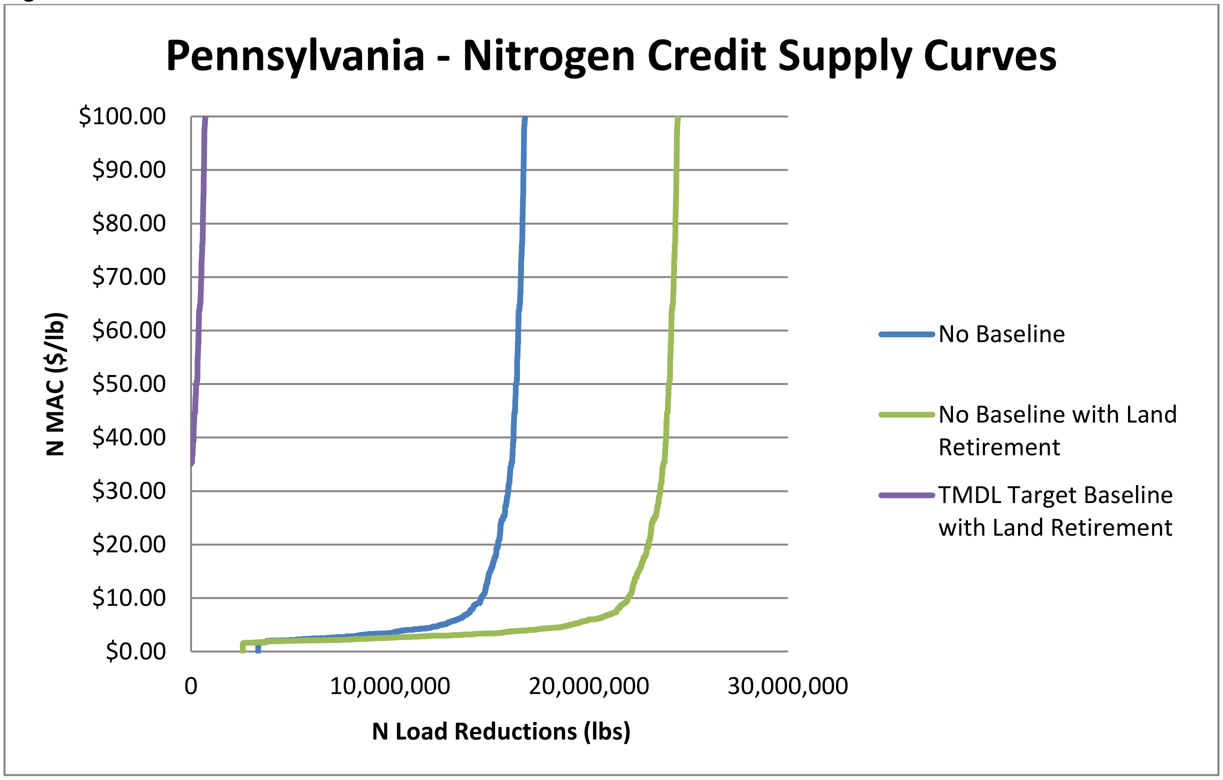

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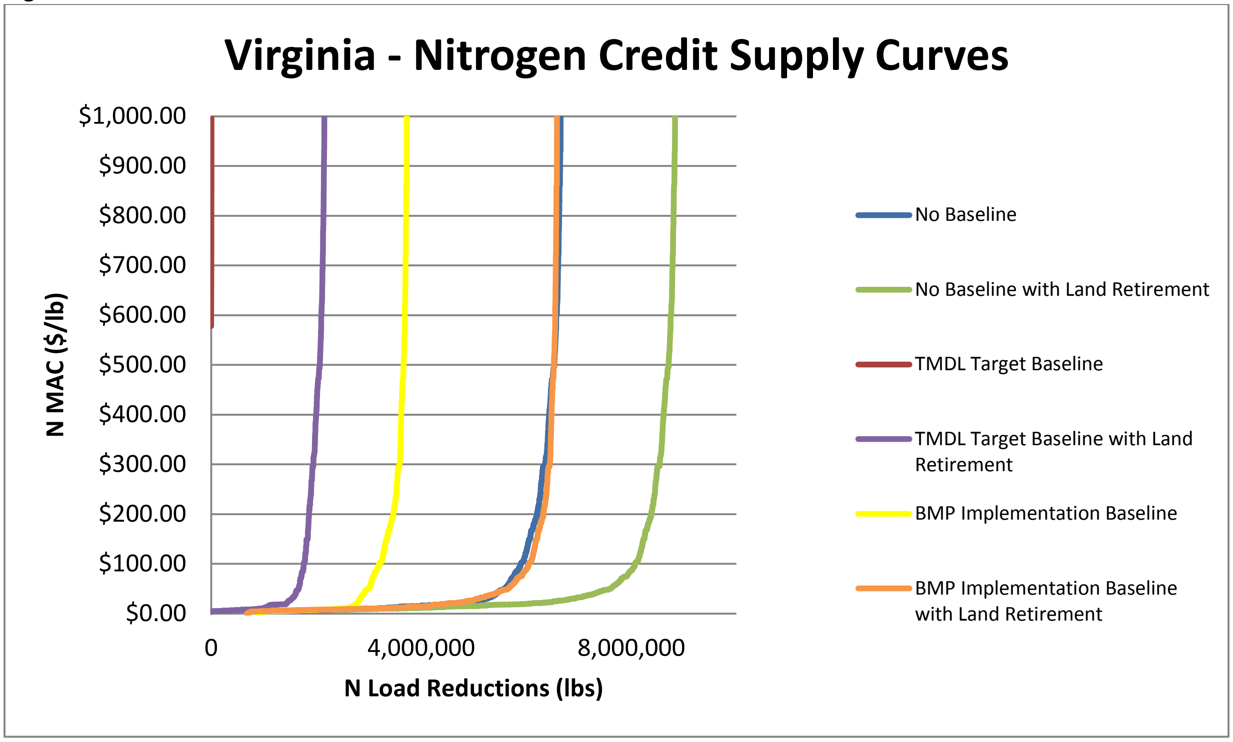


Figure 13.

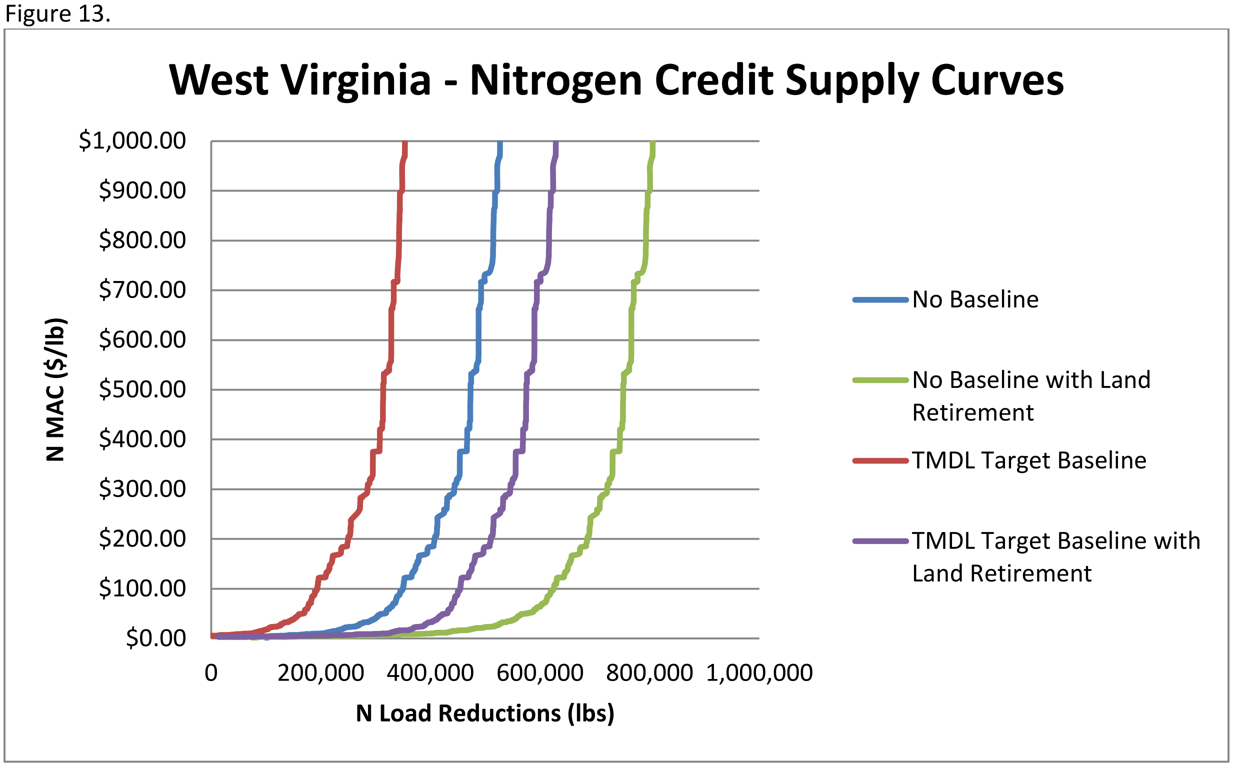


Table 7 details tradable phosphorus pounds under each baseline for scenarios one and two. Jurisdiction-specific credit supply curves associated with each baseline and scenario can be found in Figures 14 – 19. As with nitrogen, a BMP baseline scenario is also included for Virginia. As we saw with nitrogen, the more restrictive TMDL baseline results in fewer tradable pounds of phosphorus for both scenarios. The least cost reductions are devoted to achieving the TMDL target baseline. Scenario one for Pennsylvania and Virginia does not include a MAC curve for the TMDL target baseline as there are no tradable pounds of phosphorus associated with this baseline.

There is an increase in the total number of tradable pounds of phosphorus when land retirement is included. Without a baseline, the number of tradable credits initially increases when land retirement is included. However, as the MAC threshold becomes more stringent, the number of tradable credits without land retirement eventually surpasses those with land retirement. As with nitrogen, this is because including land retirement, while increasing the overall supply of credits, reduces the scale of implementation of some low-cost BMPs. Maryland is the only jurisdiction where this pattern is repeated for the TMDL target baseline. The remainder of the jurisdictions see an increase in tradable credits when land retirement is included under the TMDL baseline. This is because there are few excess pounds of phosphorus beyond the TMDL load reduction target for most jurisdictions utilizing scenario one BMPs.

If there is no baseline, Pennsylvania and Virginia are the largest sources of low-cost phosphorus reductions for both scenarios one and two. Our scenario one reductions were unable to meet the TMDL load reduction targets for these states, but that was a result of much higher load reduction targets as compared to other states. Maryland is also a significant source of credits. Circumstances are different for the TMDL target baseline. For scenario one, Maryland is the only significant source of tradable phosphorus credits below $100/lb. There are small numbers of tradable credits (fewer than 7,000) at less than $100/lb in New York and West Virginia. Maryland is once again the largest supplier of tradable phosphorus credits under scenario two. However, the number of tradable credits increases substantially in Pennsylvania under scenario two for the TMDL target baseline from 0 to about 200,000 in total.

We once again use the EPA limit of 200,000 pounds of tradable phosphorus across the CBW as an example case. If there is no baseline, both scenarios one and two indicate more than 600,000 pounds of tradable phosphorus credits below $10/lb, with approximately 78% of these credits sourced from Pennsylvania and Virginia. There are more than 200,000 tradable pounds of P in each of Pennsylvania and Virginia at this price. With a TMDL target baseline, there are approximately 200,000 pounds of tradable phosphorus credits at a MAC less than $45/lb for scenario one. For scenario two, there are approximately 200,000 pounds of tradable phosphorus credits at a MAC less than $40/lb.

Table 7 – Summary of Tradable Phosphorus Loads at Various MAC Thresholds: Scenario One and Scenario Two

Phosphorus Tradable Pounds	Scenario One (No Land Retirement)			Scenario Two (Land Retirement		
DELAWARE	**No Baseline**	**TMDL Target Baseline**		**No Baseline**	**TMDL Target Baseline**	
Total Tradable Pounds	53,914	8,102		90,908	43,365	
Tradable lbs Below $100/lb	43,796	0		70,212	22,669	
Tradable lbs Below $50/lb	33,429	0		35,650	0	
Tradable lbs Below $30/lb	22,834	0		22,192	0	
Tradable lbs Below $10/lb	20,113	0		19,646	0	
MARYLAND	**No Baseline**	**TMDL Target Baseline**		**No Baseline**	**TMDL Target Baseline**	
Total Tradable Pounds	350,007	265,949		525,813	441,127	
Tradable lbs Below $100/lb	316,305	232,259		367,277	286,104	
Tradable lbs Below $50/lb	286,487	203,187		279,275	199,535	
Tradable lbs Below $30/lb	161,935	81,656		144,982	80,246	
Tradable lbs Below $10/lb	67,512	0		52,240	0	
NEW YORK	**No Baseline**	**TMDL Target Baseline**		**No Baseline**	**TMDL Target Baseline**	
Total Tradable Pounds	147,188	37,836		178,231	68,450	
Tradable lbs Below $100/lb	109,597	6,931		99,080	31,973	
Tradable lbs Below $50/lb	91,064	2,434		81,944	22,976	
Tradable lbs Below $30/lb	51,142	0		39,787	0	
Tradable lbs Below $10/lb	50,945	0		39,590	0	
PENNSYLVANIA - ALL BASINS	**No Baseline**	**TMDL Target Baseline**		**No Baseline**	**TMDL Target Baseline**	
Total Tradable Pounds	777,541	0		1,008,264	214,279	
Tradable lbs Below $100/lb	625,034	0		693,641	57,587	
Tradable lbs Below $50/lb	534,587	0		537,519	34,535	
Tradable lbs Below $30/lb	429,797	0		344,746	13,604	
Tradable lbs Below $10/lb	271,717	0		215,673	0	
WEST VIRGINIA - ALL BASINS	**No Baseline**	**TMDL Target Baseline**		**No Baseline**	**TMDL Target Baseline**	
Total Tradable Pounds	138,851	84,424		160,509	107,941	
Tradable lbs Below $100/lb	43,339	6,010		52,185	13,154	
Tradable lbs Below $50/lb	38,104	5,045		47,837	11,563	
Tradable lbs Below $30/lb	35,756	4,980		29,003	7,070	
Tradable lbs Below $10/lb	28,451	0		21,702	0	
VIRGINIA - ALL BASINS	**No Baseline**	**TMDL Target Baseline**	**BMP Baseline**	**No Baseline**	**TMDL Target Baseline**	**BMP Baseline**
Total Tradable Pounds	1,140,543	0	827,601	1,917,510	63,792	1,667,612
Tradable lbs Below $100/lb	736,134	0	562,512	1,288,845	0	1,157,714
Tradable lbs Below $50/lb	690,650	0	552,889	889,427	0	785,261
Tradable lbs Below $30/lb	618,136	0	523,917	642,895	0	571,090
Tradable lbs Below $10/lb	314,102	0	299,949	257,400	0	246,742

Figure 14.

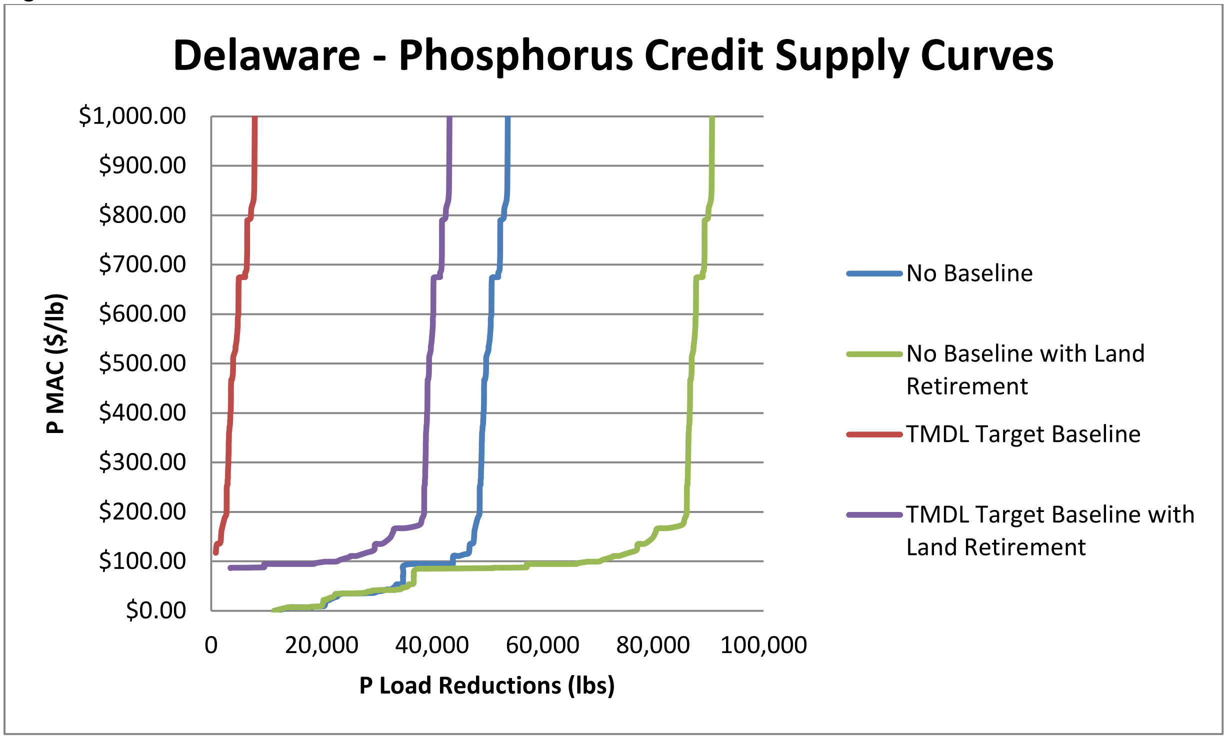
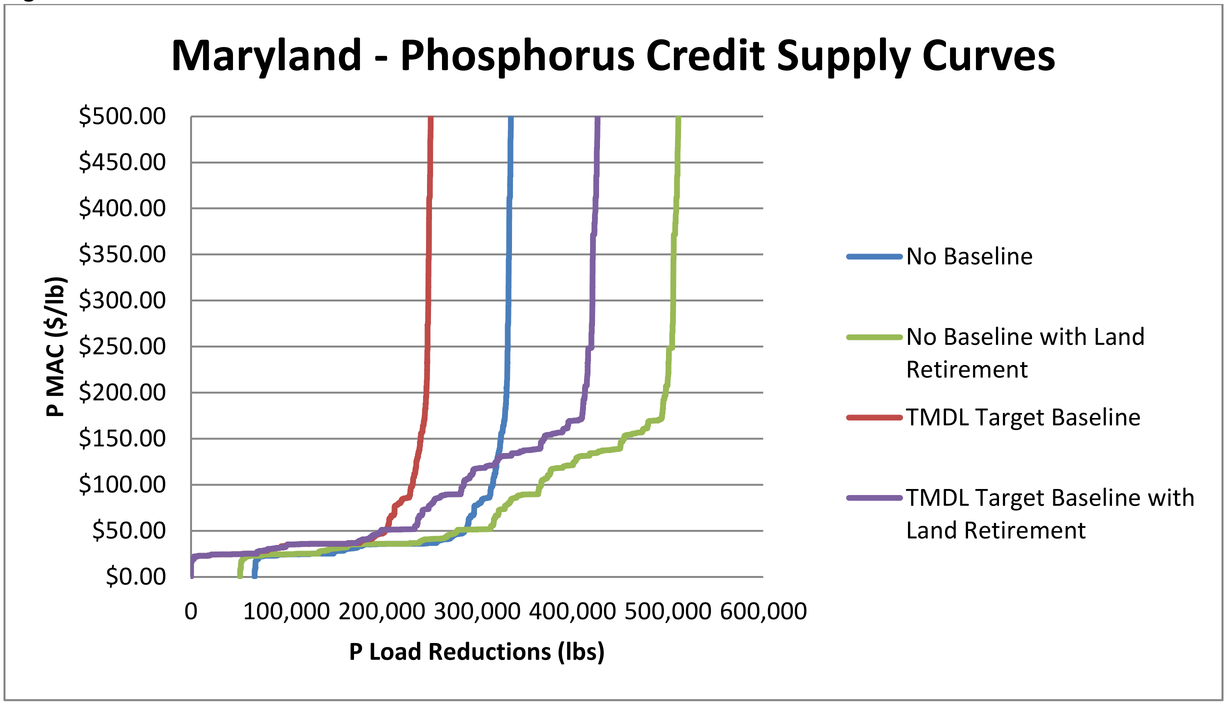


Figure 15.



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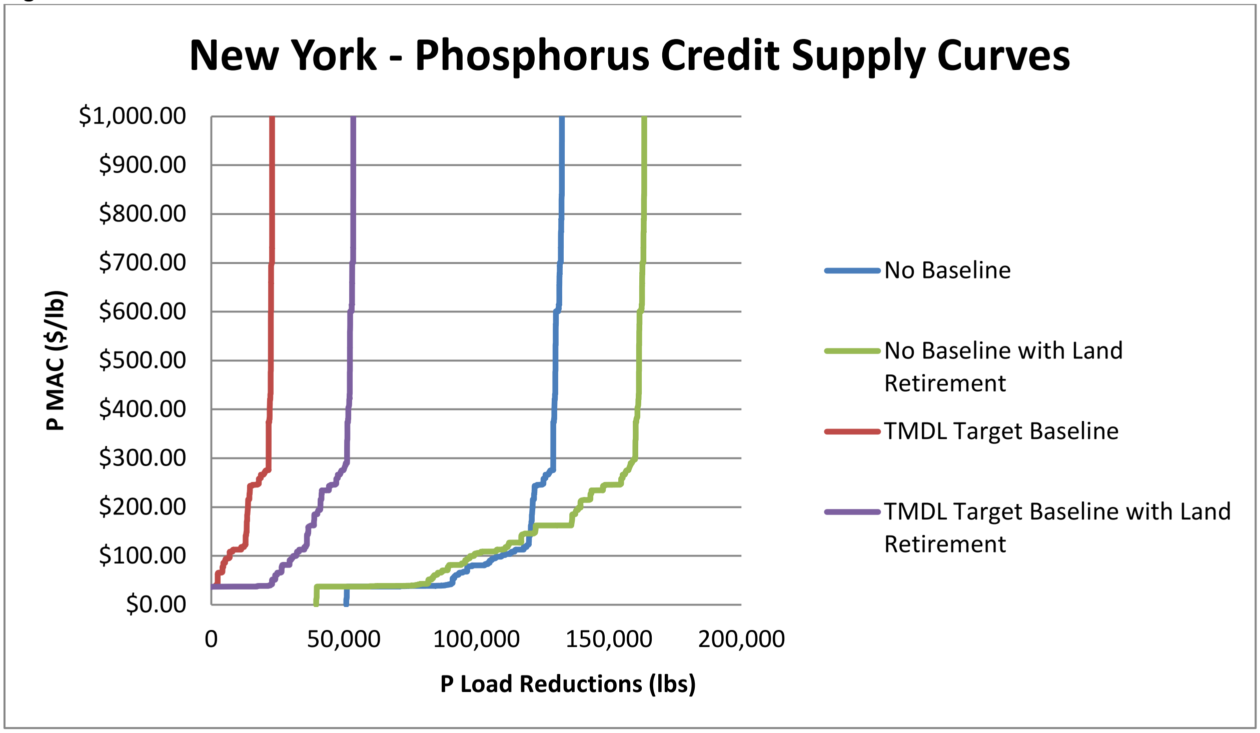


Figure 17.

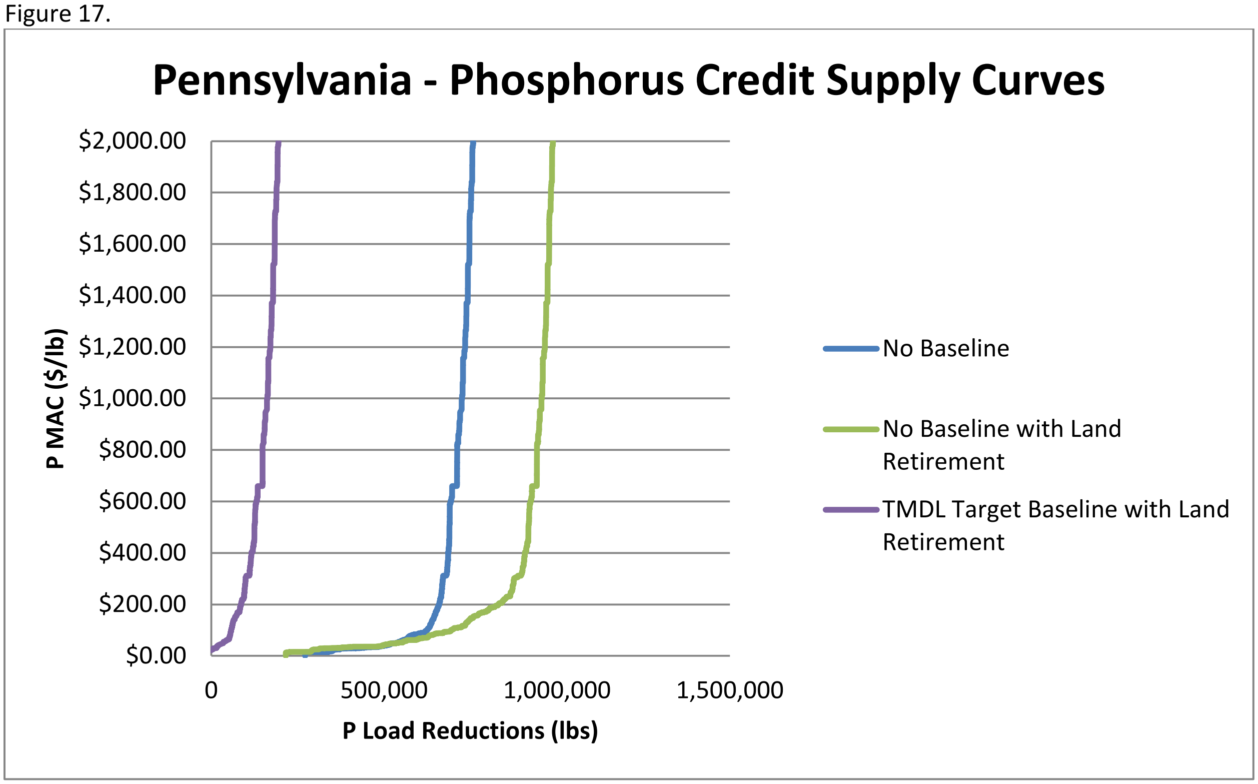


Figure 18.

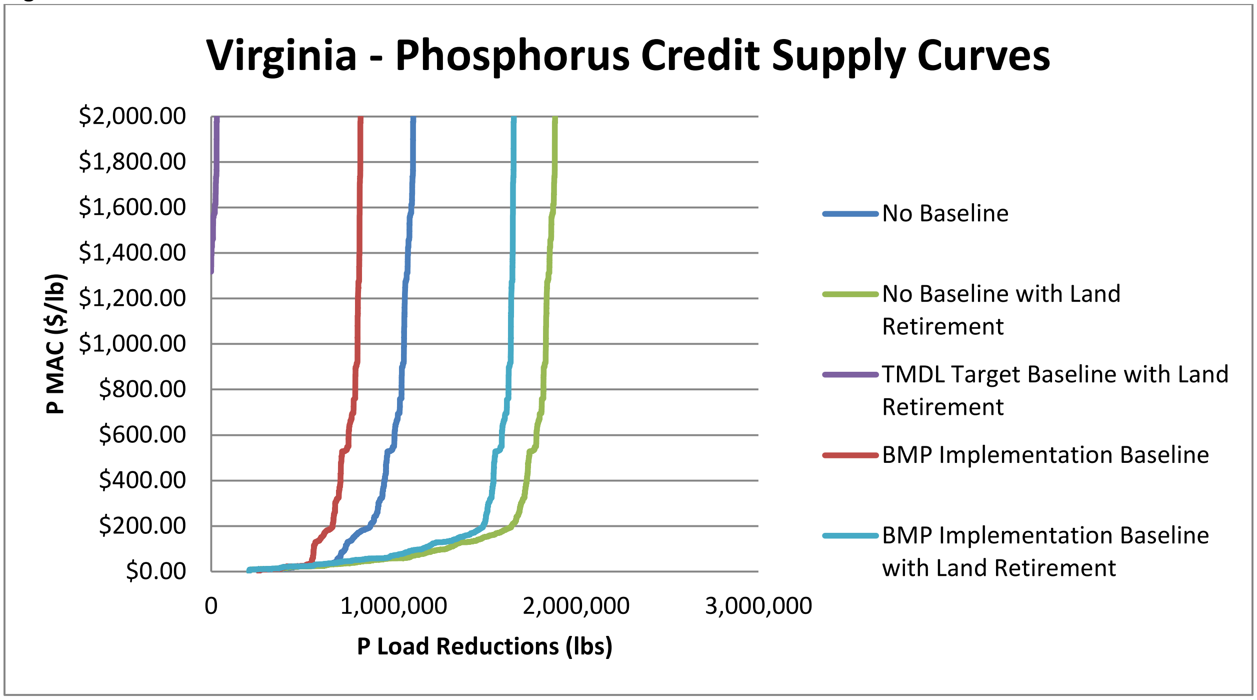
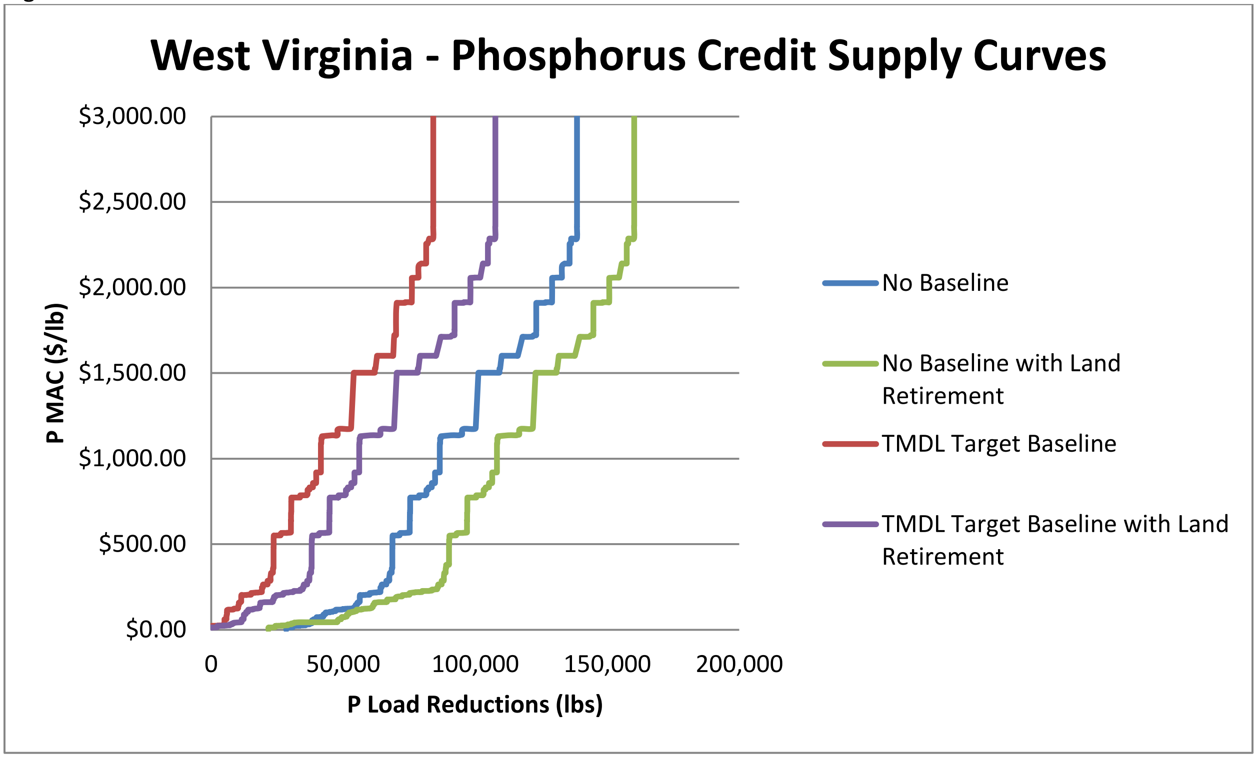


Figure 19.



Conclusions

The Chesapeake Bay TMDL WIPs for agriculture include a wide variety of conservation practices, from structural practices with long lifespans to non-structural practices requiring implementation on an annual basis. The selection and location of these practices has important impacts on the achievement of water quality goals. The results from this project demonstrate that selection and location also substantially affect economic costs. A cost-effective implementation of BMPs across land-river segments in the CBW can yield cost reductions in the tens of millions of dollars annually in nearly every state while simultaneously meeting or exceeding TMDL pollution reduction targets.

We analyzed cost-effective implementation portfolios without land retirement (scenario one) and with land retirement (scenario two). When incorporating land retirement as a BMP, we assumed that 25% of applicable agricultural acres were converted to either hay without nutrients, or forest, in each land-river segment. Our analysis indicates cost savings in Delaware of $15.5 million for scenario one, an 80% reduction as compared to WIP costs, and $15.9 million for scenario two, an 82% reduction. Cost savings in Maryland are about $70 million for both scenarios, an 84% reduction. Results for New York indicate cost savings of $19.4 million as compared to annual WIP costs for scenario one, or 27%. Upon including land retirement, cost savings increase substantially to approximately $61 million, or 86%. Cost savings in West Virginia are approximately $27.2 million for scenario one, a 62% reduction, and $6 million for scenario two, a reduction of 86%. In Pennsylvania and Virginia, the suite of BMPs in scenario one results in reductions that do not meet all TMDL load reduction targets. However, both states see significant cost savings for scenario two. In Pennsylvania, scenario two costs are approximately $276 million less than estimated WIP costs, a 73% cost reduction. Scenario two cost savings in Virginia are approximately $84 million, a reduction of 27%. For the entire Chesapeake Bay Watershed, results indicate annual cost savings for scenario one of approximately $269 million, or 30%, and $545 million, or 60%, for scenario two.

Our analysis provides results and an analytical tool that could be useful for government agencies involved in pollution control planning and charged with BMP implementation responsibilities. Our analysis assumes full implementation of practices beyond those already implemented in the 2011 CBP progress baseline, which may not be a realistic assumption. However, the cost-effective ordering of BMPs across space and BMP type still holds even with partial implementation.

The results of our analysis can be refined to create a useful tool for NRCS planners and conservation professionals. With continued development, the spatial scale of this tool could be improved since land-river segments are the basis for BMP implementation. For example, conservation planners could focus only on land-river segments in their major basin or across a county or selection of counties. At each of these spatial scales, planners could identify the most efficient locations and types of practices according to the CBP data on which results are based.

There are significant potential gains to trade. Our trading analysis indicates that tradable loads are highly contingent on the baseline chosen for trading for both scenarios. If there is no baseline, the lowest MAC practices are eligible for credit generation, thus allowing larger cost savings associated with nutrient trading. However, if jurisdictions must first reach their TMDL pollution reduction targets before generating credits, many of the lowest cost MAC practices are not available for trading. Maryland serves as a useful example, as results indicate significant numbers of tradable pounds of N and P across all baselines and scenarios. With no baseline, there are over 5 million and 7.2 million tradable pounds of N at a MAC of less than $10/lb for scenarios one and two, respectively. Tradable pounds of N with a MAC less than $10/lb decrease to 1.5 million and 3.7 million for scenarios one and two, respectively, with a TMDL target baseline. With no baseline, there are over 160,000 and 145,000 pounds of tradable P at a MAC of less than $30/lb for scenarios one and two, respectively. With a TMDL target baseline, tradable P decreases to 82,000 and 80,000 pounds at this MAC level for scenarios one and two, respectively.

As a metric of the amount of trading that could occur, EPA has suggested that 9 million pounds of nitrogen and 200,000 pounds of phosphorus can safely be traded across major basins without negatively impacting local water quality. With no baseline, this 9 million pound N trading threshold is reached at a cost of less than $5/lb, with about 17.5 million and 23.9 million tradable pounds of N under scenarios one and two, respectively. If the TMDL target baseline is adopted, the number of credits available drops significantly and the price increases under both scenarios. For scenario one, there are approximately 5.5 million tradable pounds of N available in total, while scenario two yields 9 million pounds of tradable credits at a MAC less than $30/lb. For phosphorus with no baseline, both scenarios one and two indicate more than 600,000 pounds of tradable phosphorus credits below $10/lb, with approximately 78% of these credits sourced from Pennsylvania and Virginia. With a TMDL target baseline, there are approximately 200,000 pounds of tradable P credits at a MAC less than $45/lb for scenario one and approximately 200,000 pounds of tradable P credits at a MAC less than $40/lb for scenario two.

An estimation of the POTW demand for nitrogen credits by Ribaudo et al. (2013) indicates that approximately 9 million pounds of N credits would be demanded by POTWs at a price of about $9/lb. They find the quantity demanded to more than triple at a price of about $3/lb. The quantity demanded falls to about 3.3 million pounds at a price of $16.50/lb. Depending on the baseline compliance requirements for agriculture, our analysis below shows substantial volumes of tradable nitrogen credits at these prices. We note, however, that point-nonpoint trade ratios in excess of one have the effect of a tax on credit transactions. For example, a trade ratio of 2.5:1, which has been proposed in draft requirements by the CBP, would increase the buyer's price per credit by 2.5 times the seller's price. If credits are priced competitively, this would imply credit prices 2.5 times the costs of producing credits. The Ribaudo et al. demand estimates suggest this could significantly dampen trading volumes.

Gains from point-nonpoint trading programs may be hindered by the time lag associated with some agricultural BMPs between implementation and impact on water quality in the Bay. Due to a variety of factors including distance to nearby streams and land-based characteristics, BMPs do not reduce pollution in the Bay instantaneously. Lags mean that the full impact of nutrient reductions from certain BMPs may not be realized for years or even decades in some cases. This adds uncertainty to these reductions and creates challenges for successfully designing point-nonpoint trades.

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Appendix A: Tables

Table A.1. SUMMARY OF TOTAL COSTS (through 2025; 2011 baseline) - DISCOUNTED

BMP	DELAWARE	MARYLAND	NEW YORK	PENNSYLVANIA	VIRGINIA	WEST VIRGINIA	CHESAPEAKE BAY	Percentage of Total
Alternative Watering	$0	$0	$62,476,028	$341,362,776	$0	$0	**$403,838,804**	11.16%
Ammonia Emissions Reduction - Alum	$0	$3,219,293	$0	$1,910,922	$6,020,859	$0	**$11,151,074**	0.31%
Ammonia Emissions Reduction - Bio & Lagoon	$947,502	$0	$0	$17,936,982	$0	$0	**$18,884,484**	0.52%
AWMS – Livestock	$9,227,607	$111,063,560	$13,748,864	$420,950,960	$385,802,265	$7,344,399	**$948,137,655**	26.19%
AWMS – Poultry	$12,236,596	$2,927,313	$204,429	$18,807,409	$34,851,142	$8,086,920	**$77,113,809**	2.13%
Barnyard Runoff	$660,626	$841,551	$0	$10,965,864	$9,191,767	$0	**$21,659,809**	0.60%
Capture & Reuse	$0	$11,346,585	$0	$3,737,866	$16,062,923	$0	**$31,147,374**	0.86%
Carbon Sequestration	$139,082	$66,903	$0	$5,777,938	$0	$0	**$5,983,923**	0.17%
Commodity Cover Crops	$1,608,567	$0	$84,670	$54,145,192	$24,073,562	$1,074,088	**$80,986,079**	2.24%
Conservation Plan	$1,155,373	$2,801,192	$3,057,179	$11,761,222	$7,301,436	$0	**$26,076,402**	0.72%
Conservation Tillage	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Continuous No-Till	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Cover Crops	$4,243,067	$41,314,413	$8,812,567	$52,986,820	$76,593,288	$0	**$183,950,155**	5.08%
Cropland Irrigation Management	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Dairy Precision Feeding	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Decision Agriculture	$21,032,806	$73,557,390	$3,967,564	$10,033,646	$21,160,806	$0	**$129,752,212**	3.58%
Enhanced Nutrient Management	$0	$1,919,271	$7,390,672	$58,151,893	$2,376,399	$0	**$69,838,236**	1.93%
Forest Buffers	$1,885,297	$877,233	$5,019,047	$92,831,459	$27,914,367	$1,544,374	**$130,071,777**	3.59%
Grass Buffers	$3,206,164	$670,641	$7,819,092	$20,016,200	$31,955,248	$0	**$63,667,345**	1.76%

Horse Pasture Management	$0	$526,409	$178,356	$0	$2,486,688	$0	**$3,191,453**	0.09%
Land Retirement	$369,774	$10,630,632	$1,435,653	$30,255,468	$7,228,121	$327,294	**$50,246,942**	1.39%
Liquid/Poultry Manure Injection	$0	$45,236,038	$35,968,226	$8,220,185	$0	$0	**$89,424,449**	2.47%
Loafing Lot Management	$0	$1,034,549	$3,243,653	$0	$0	$0	**$4,278,202**	0.12%
Manure Transport - Inside CBWS	$0	$1,414,143	$0	$0	$743,987	$0	**$2,158,130**	0.06%
Manure Transport - Outside CBWS	$10,422,726	$1,914,487	$0	$24,387,431	$8,500,860	$2,504,407	**$47,729,911**	1.32%
Mortality Composters	$0	$0	$1,215,386	$7,551,896	$91,016,242	$3,101,418	**$102,884,942**	2.84%
Nutrient Management	$0	$0	$0	$0	$3,359,442	$2,753,660	**$6,113,101**	0.17%
Poultry Phytase	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Swine Phytase	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Precision Intensive Rotational Grazing	$242,412	$1,042,581	$0	$105,593,929	$0	$0	**$106,878,922**	2.95%
Prescribed Grazing	$0	$936,148	$7,888,320	$4,118,190	$33,035,010	$0	**$45,977,667**	1.27%
Stream Access Control w/ Fencing	$0	$6,074,295	$99,388,242	$116,052,621	$377,493,511	$148,782,713	**$747,791,383**	20.66%
Stream Restoration	$2,036,833	$2,384,019	$8,128,973	$1,389,256	$3,039,345	$371,276	**$17,349,702**	0.48%
Tree Planting	$185,583	$3,785,456	$101,795	$19,563,604	$37,025,048	$0	**$60,661,486**	1.68%
Water Control Structures	$848,629	$1,261,535	$0	$0	$44,599	$0	**$2,154,763**	0.06%
Wetland Restoration	$7,312,476	$5,798,872	$15,208,966	$77,665,848	$24,870,591	$262,681	**$131,119,435**	3.62%
Totals:	**$77,761,121**	**$332,644,508**	**$285,337,683**	**$1,516,175,577**	**$1,232,147,506**	**$176,153,230**	**$3,620,219,626**	100.00%

Table A.2. SUMMARY OF TOTAL COSTS (through 2025; 2009 baseline) - DISCOUNTED

BMP	DELAWARE	MARYLAND	NEW YORK	PENNSYLVANIA	VIRGINIA	WEST VIRGINIA	CHESAPEAKE BAY	Percentage of Total
Alternative Watering	$2,758,707	$94,356,424	$68,926,197	$546,169,384	$0	$14,573,492	**$726,784,204**	14.46%
Ammonia Emissions Reduction - Alum	$0	$3,361,835	$0	$1,995,532	$18,076,410	$0	**$23,433,778**	0.47%
Ammonia Emissions Reduction - Bio & Lagoon	$989,453	$0	$0	$18,731,186	$0	$0	**$19,720,639**	0.39%
AWMS – Livestock	$9,404,291	$126,610,725	$29,178,929	$466,074,880	$411,001,874	$0	**$1,042,270,699**	20.74%
AWMS – Poultry	$14,592,110	$6,801,722	$224,207	$21,570,696	$39,329,132	$13,926,945	**$96,444,812**	1.92%
Barnyard Runoff	$709,384	$1,324,302	$1,209,374	$12,319,364	$10,263,766	$0	**$25,826,190**	0.51%
Capture & Reuse	$0	$11,848,982	$0	$3,903,369	$16,774,148	$0	**$32,526,499**	0.65%
Carbon Sequestration	$145,240	$69,865	$0	$6,017,582	$0	$0	**$6,232,687**	0.12%
Commodity Cover Crops	$2,341,153	$0	$524,325	$56,542,602	$23,179,370	$1,121,646	**$83,709,096**	1.67%
Conservation Plan	$1,770,273	$3,445,807	$3,403,973	$14,350,017	$8,731,765	$0	**$31,701,836**	0.63%
Conservation Tillage	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Continuous No-Till	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Cover Crops	$8,369,416	$78,340,624	$8,989,505	$33,274,480	$81,819,102	$2,005,919	**$212,799,045**	4.23%
Cropland Irrigation Management	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Dairy Precision Feeding	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Decision Agriculture	$21,964,085	$76,814,322	$4,143,238	$10,477,910	$22,097,752	$0	**$135,497,306**	2.70%
Enhanced Nutrient Management	$0	$7,221,302	$8,721,257	$60,732,264	$2,579,336	$0	**$79,254,159**	1.58%
Forest Buffers	$1,968,773	$1,656,520	$5,609,991	$125,152,132	$29,817,104	$2,260,023	**$166,464,544**	3.31%
Grass Buffers	$3,357,847	$1,758,360	$10,247,813	$22,020,129	$34,771,295	$8,783	**$72,164,227**	1.44%

Horse Pasture Management	$0	$549,717	$189,075	$0	$2,596,792	$0	**$3,335,584**	0.07%
Land Retirement	$425,295	$12,107,378	$1,504,020	$68,824,909	$9,228,194	$611,288	**$92,701,083**	1.84%
Liquid/Poultry Manure Injection	$0	$47,238,973	$37,560,807	$8,584,154	$0	$0	**$93,383,934**	1.86%
Loafing Lot Management	$0	$1,080,356	$3,371,818	$0	$0	$0	**$4,452,173**	0.09%
Manure Transport - Inside CBWS	$0	$0	$0	$0	$5,012,795	$0	**$5,012,795**	0.10%
Manure Transport - Outside CBWS	$11,063,872	$0	$0	$20,810,473	$17,112,644	$2,483,926	**$51,470,914**	1.02%
Mortality Composters	$3,241,821	$2,017,556	$1,286,195	$8,763,464	$107,957,204	$3,238,740	**$126,504,980**	2.52%
Nutrient Management	$0	$0	$0	$0	$857,410	$0	**$857,410**	0.02%
Poultry Phytase	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Swine Phytase	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Precision Intensive Rotational Grazing	$253,145	$1,088,743	$0	$110,269,357	$0	$0	**$111,611,246**	2.22%
Prescribed Grazing	$0	$1,123,811	$8,493,537	$4,844,332	$36,439,726	$172,681	**$51,074,087**	1.02%
Stream Access Control w/ Fencing	$0	$9,124,962	$269,610,936	$304,037,803	$541,822,312	$361,932,368	**$1,486,528,382**	29.58%
Stream Restoration	$2,127,019	$2,489,577	$8,488,903	$9,070,683	$3,173,920	$635,934	**$25,986,035**	0.52%
Tree Planting	$308,701	$7,633,032	$116,124	$22,349,523	$42,410,718	$466,667	**$73,284,764**	1.46%
Water Control Structures	$886,204	$1,382,733	$0	$0	$57,195	$0	**$2,326,132**	0.05%
Wetland Restoration	$8,055,462	$7,371,414	$17,285,209	$82,276,333	$26,244,861	$274,584	**$141,507,862**	2.82%
Totals:	**$94,732,251**	**$506,819,042**	**$489,085,431**	**$2,039,162,558**	**$1,491,354,824**	**$403,712,997**	**$5,024,867,103**	100.00%

Table A.3. Annual Costs of all new WIP implementation beyond 2011 Baseline

BMP	DELAWARE	MARYLAND	NEW YORK	PENNSYLVANIA	VIRGINIA	WEST VIRGINIA	CHESAPEAKE BAY	Percentage of Total
Alternative Watering	$0	$0	$15,586,366	$85,162,345	$0	$0	**$100,748,710**	11.16%
Ammonia Emissions Reduction - Alum	$0	$803,141	$0	$476,732	$1,502,069	$0	**$2,781,942**	0.31%
Ammonia Emissions Reduction - Bio & Lagoon	$236,380	$0	$0	$4,474,874	$0	$0	**$4,711,255**	0.52%
AWMS – Livestock	$2,302,081	$27,707,864	$3,430,033	$105,017,809	$96,248,999	$1,832,262	**$236,539,047**	26.19%
AWMS – Poultry	$3,052,756	$730,299	$51,000	$4,692,026	$8,694,577	$2,017,505	**$19,238,163**	2.13%
Barnyard Runoff	$164,811	$209,948	$0	$2,735,737	$2,293,139	$0	**$5,403,636**	0.60%
Capture & Reuse	$0	$2,830,718	$0	$932,514	$4,007,339	$0	**$7,770,570**	0.86%
Carbon Sequestration	$34,698	$16,691	$0	$1,441,466	$0	$0	**$1,492,854**	0.17%
Commodity Cover Crops	$401,301	$0	$21,123	$13,508,009	$6,005,813	$267,961	**$20,204,207**	2.24%
Conservation Plan	$288,240	$698,834	$762,698	$2,934,161	$1,821,544	$0	**$6,505,477**	0.72%
Conservation Tillage	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Continuous No-Till	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Cover Crops	$1,058,550	$10,307,018	$2,198,537	$13,219,021	$19,108,305	$0	**$45,891,432**	5.08%
Cropland Irrigation Management	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Dairy Precision Feeding	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Decision Agriculture	$5,247,213	$18,350,916	$989,818	$2,503,169	$5,279,146	$0	**$32,370,262**	3.58%
Enhanced Nutrient Management	$0	$478,815	$1,843,807	$14,507,591	$592,858	$0	**$17,423,071**	1.93%
Forest Buffers	$470,339	$218,850	$1,252,140	$23,159,364	$6,964,007	$385,287	**$32,449,987**	3.59%
Grass Buffers	$799,866	$167,310	$1,950,688	$4,993,592	$7,972,117	$0	**$15,883,572**	1.76%

Horse Pasture Management	$0	$131,327	$44,496	$0	$620,373	$0	**$796,196**	0.09%
Land Retirement	$92,250	$2,652,104	$358,163	$7,548,060	$1,803,254	$81,653	**$12,535,483**	1.39%
Liquid/Poultry Manure Injection	$0	$11,285,375	$8,973,264	$2,050,752	$0	$0	**$22,309,391**	2.47%
Loafing Lot Management	$0	$258,097	$809,219	$0	$0	$0	**$1,067,315**	0.12%
Manure Transport - Inside CBWS	$0	$352,797	$0	$0	$185,608	$0	**$538,405**	0.06%
Manure Transport - Outside CBWS	$2,600,236	$477,622	$0	$6,084,116	$2,120,774	$624,793	**$11,907,541**	1.32%
Mortality Composters	$0	$0	$303,212	$1,884,028	$22,706,508	$773,734	**$25,667,482**	2.84%
Nutrient Management	$0	$0	$0	$0	$838,105	$686,976	**$1,525,081**	0.17%
Poultry Phytase	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Swine Phytase	$0	$0	$0	$0	$0	$0	**$0**	0.00%
Precision Intensive Rotational Grazing	$60,476	$260,100	$0	$26,343,313	$0	$0	**$26,663,890**	2.95%
Prescribed Grazing	$0	$233,548	$1,967,959	$1,027,396	$8,241,493	$0	**$11,470,395**	1.27%
Stream Access Control w/ Fencing	$0	$1,515,400	$24,795,134	$28,952,522	$94,176,152	$37,117,945	**$186,557,153**	20.66%
Stream Restoration	$508,144	$594,759	$2,027,996	$346,588	$758,248	$92,625	**$4,328,361**	0.48%
Tree Planting	$46,299	$944,386	$25,396	$4,880,680	$9,236,918	$0	**$15,133,678**	1.68%
Water Control Structures	$211,714	$314,725	$0	$0	$11,126	$0	**$537,565**	0.06%
Wetland Restoration	$1,824,298	$1,446,688	$3,794,295	$19,375,884	$6,204,654	$65,533	**$32,711,354**	3.62%
Totals:	**$19,399,653**	**$82,987,333**	**$71,185,343**	**$378,251,749**	**$307,393,126**	**$43,946,274**	**$903,163,477**	100.00%

Table A.4 – Delaware Cost-Effective BMP Portfolio: No Land Retirement Scenario

BMP	Total Cost ($/yr)	N Load Reductions (lbs/yr)	P Load Reductions (lbs/yr)	TSS Load Reductions (lbs/yr)
Ammonia Emissions Reduction – Biofilters*	$0	0	0	0
Animal Waste Management Systems - Livestock	$0	0	0	0
Animal Waste Management Systems - Poultry	$1,078,395	36,567	11,020	0
Barnyard Runoff Control	$112,506	81,740	10,348	12,489
Capture and Reuse	$173,816	14,769	4,606	0
Conservation Plans	$313,030	48,051	7,991	4,109,158
Conservation Tillage	$0	7,227	1,146	2,325,303
Continuous No Till Alone	$0	0	0	0
Continuous No-Till & Conservation Tillage	$0	0	0	0
Cover Crops	$0	0	0	0
Cropland Irrigation Management	$0	107,739	0	0
Dairy Precision Feeding and Forage Management	$0	5,999	1,037	0
Nutrient Management – N Target	$0	2,796	0	0
Nutrient Management – P Target	$0	0	724	0
Phytase - Poultry	$0	0	8,901	0
Phytase - Swine	$0	0	40	0
Prescribed Grazing	$0	0	0	0
Water Control Structures	$2,261,396	577,311	0	0
Totals: Cost-Effective BMP Implementation	**$3,939,143**	**882,199**	**45,812**	**6,446,949**
	Estimated WIP Cost ($/yr)	**TMDL N Reduction Target (lbs/yr)**	**TMDL P Reduction Target (lbs/yr)**	**TMDL TSS Reduction Target (lbs/yr)**
WIP/CBM TMDL Data	**$19,399,653**	**870,449**	**44,432**	**-9,439,601**

*practices highlighted in red were excluded due to elimination of high MAC BMP implementations

Table A.5 – Maryland Cost-Effective BMP Portfolio: No Land Retirement Scenario

BMP	Total Cost ($/yr)	N Load Reductions (lbs/yr)	P Load Reductions (lbs/yr)	TSS Load Reductions (lbs/yr)
Ammonia Emissions Reduction - Biofilters *	$0	0	0	0
Animal Waste Management Systems - Livestock	$0	0	0	0
Animal Waste Management Systems - Poultry	$0	0	0	0
Barnyard Runoff Control	$15,608	8,571	1,111	4,391
Capture and Reuse	$704,582	159,789	27,142	0
Conservation Plans	$579,468	137,475	16,105	12,279,007
Conservation Tillage	$0	41,503	3,739	8,704,324
Continuous No Till Alone	$0	317,281	48,384	67,649,214
Continuous No-Till & Conservation Tillage	$0	65,307	8,967	20,820,632
Cover Crops	$1,319,121	241,983	144	242,675
Cropland Irrigation Management	$0	371,542	0	0
Dairy Precision Feeding and Forage Management	$0	19,341	2,837	0
Enhanced Nutrient Management – N Target	$2,182	362	0	0
Nutrient Management – N Target	$43,746	9,067	0	0
Phytase - Poultry	$0	0	2,758	0
Phytase - Swine	$0	0	84	0
Prescribed Grazing	$15,545	2,584	212	1,544
Stream Access Control	$0	0	0	0
Water Control Structures	$10,160,924	2,195,548	0	0
Totals: Cost-Effective BMP Implementation	**$12,841,176**	**3,570,353**	**111,483**	**109,701,787**
	Estimated WIP Cost ($/yr)	**TMDL N Reduction Target (lbs/yr)**	**TMDL P Reduction Target (lbs/yr)**	**TMDL TSS Reduction Target (lbs/yr)**
WIP/CBM TMDL Data	**$82,987,333**	**3,559,095**	**83,009**	**-131,929,541**

*practices highlighted in red were excluded due to elimination of high MAC BMP implementations

Table A.6 – New York Cost-Effective BMP Portfolio: No Land Retirement Scenario

BMP	Total Cost ($/yr)	N Load Reductions (lbs/yr)	P Load Reductions (lbs/yr)	TSS Load Reductions (lbs/yr)
Ammonia Emissions Reduction - Biofilters	$6,574,734	112,470	0	0
Animal Waste Management Systems - Livestock	$8,295,404	15,679	6,821	0
Animal Waste Management Systems - Poultry	$119,821	469	304	0
Barnyard Runoff Control	$138,704	12,376	2,311	59,327
Capture and Reuse	$1,621,366	86,689	40,860	0
Conservation Plans	$1,548,357	107,287	17,490	7,152,416
Conservation Tillage	$0	17,940	3,865	1,707,222
Continuous No Till Alone	$0	13,786	2,058	1,038,781
Continuous No-Till & Conservation Tillage	$0	278,203	39,497	27,830,285
Cover Crops	$3,968,847	249,209	2,129	942,620
Dairy Precision Feeding and Forage Management	$0	29,277	5,400	0
Enhanced Nutrient Management – N Target	$2,475,065	74,207	0	0
Nutrient Management – N Target	$401,098	16,304	0	0
Nutrient Management – P Target*	$0	0	0	0
Phytase - Poultry	$0	0	62	0
Phytase - Swine	$0	0	64	0
Prescribed Grazing	$2,223,650	36,288	8,413	2,721,919
Stream Access Control	$24,482,193	45,516	6,395	1,262,327
Totals: Cost-Effective BMP Implementation	**$51,849,239**	**1,095,700**	**135,669**	**42,714,897**
	Estimated WIP Cost ($/yr)	**TMDL N Reduction Target (lbs/yr)**	**TMDL P Reduction Target (lbs/yr)**	**TMDL TSS Reduction Target (lbs/yr)**
WIP/CBM TMDL Data	**$71,185,343**	**1,095,424**	**108,885**	**18,313,970**

*practices highlighted in red were excluded due to elimination of high MAC BMP implementations

Table A.7 – Pennsylvania Cost-Effective BMP Portfolio: No Land Retirement Scenario

BMP	Total Cost ($/yr)	N Load Reductions (lbs/yr)	P Load Reductions (lbs/yr)	TSS Load Reductions (lbs/yr)
Ammonia Emissions Reduction - Biofilters	$44,748,729	1,249,631	0	0
Animal Waste Management Systems - Livestock	$97,809,793	228,229	64,945	0
Animal Waste Management Systems - Poultry	$278,741	3,179	739	0
Barnyard Runoff Control	$3,435,871	491,053	53,410	4,177,560
Capture and Reuse	$9,458,602	1,566,808	248,716	0
Conservation Plans	$3,570,367	877,792	52,053	53,217,796
Conservation Tillage	$0	413,469	11,911	64,878,858
Continuous No Till Alone	$0	1,050,922	77,345	108,425,851
Continuous No-Till & Conservation Tillage	$0	1,440,981	85,868	196,295,200
Cover Crops	$28,142,503	8,204,046	8,449	9,964,219
Dairy Precision Feeding and Forage Management	$0	282,544	38,308	0
Enhanced Nutrient Management – N Target	$3,222,145	310,006	0	0
Nutrient Management – N Target	$0	191,091	0	0
Nutrient Management – P Target	$0	0	49,054	0
Phytase - Poultry	$0	0	5,904	0
Phytase - Swine	$0	0	3,327	0
Prescribed Grazing	$7,458,625	368,059	47,109	15,615,648
Stream Access Control	$43,157,808	505,272	30,402	2,905,217
Totals: Cost-Effective BMP Implementation	**$241,283,184**	**17,183,082**	**777,540**	**455,480,349**
	Estimated WIP Cost ($/yr)	**TMDL N Reduction Target (lbs/yr)**	**TMDL P Reduction Target (lbs/yr)**	**TMDL TSS Reduction Target (lbs/yr)**
WIP/CBM TMDL Data	**$378,251,749**	**23,735,408**	**793,940**	**466,487,022**

Table A.8 – West Virginia Cost-Effective BMP Portfolio: No Land Retirement Scenario

BMP	Total Cost ($/yr)	N Load Reductions (lbs/yr)	P Load Reductions (lbs/yr)	TSS Load Reductions (lbs/yr)
Ammonia Emissions Reduction – Biofilters*	$0	0	0	0
Animal Waste Management Systems - Livestock	$0	0	0	0
Animal Waste Management Systems - Poultry	$0	0	0	0
Barnyard Runoff Control	$215,000	8,368	5,297	699,013
Capture and Reuse	$11,912	2,589	463	0
Conservation Plans	$76,735	5,624	1,405	1,169,502
Conservation Tillage	$0	732	145	110,510
Continuous No Till Alone	$0	67,594	11,104	3,479,795
Continuous No-Till & Conservation Tillage	$0	30,897	15,748	3,284,705
Cover Crops	$5,452	334	8	14,462
Dairy Precision Feeding and Forage Management	$0	2,439	365	0
Enhanced Nutrient Management – N Target	$83,492	16,233	0	0
Nutrient Management – N Target	$0	0	0	0
Nutrient Management – P Target	$0	0	0	0
Phytase - Poultry	$0	0	1,085	0
Phytase - Swine	$0	0	4	0
Prescribed Grazing	$1,045,500	23,275	9,857	11,086,959
Stream Access Control	$15,352,058	19,287	9,409	20,944,718
Totals: Cost-Effective BMP Implementation	**$16,790,149**	**177,372**	**54,890**	**40,789,664**
	Estimated WIP Cost ($/yr)	**TMDL N Reduction Target (lbs/yr)**	**TMDL P Reduction Target (lbs/yr)**	**TMDL TSS Reduction Target (lbs/yr)**
WIP/CBM TMDL Data	**$43,946,274**	**176,741**	**52,527**	**34,724,975**

*practices highlighted in red were excluded due to elimination of high MAC BMP implementations

Table A.9 – Delaware Cost-Effective BMP Portfolio: Land Retirement Scenario

BMP	Total Cost ($/yr)	N Load Reductions (lbs/yr)	P Load Reductions (lbs/yr)	TSS Load Reductions (lbs/yr)
Ammonia Emissions Reduction – Biofilters*	$0	0	0	0
AWMS - Livestock	$0	0	0	0
AWMS - Poultry	$0	0	0	0
Barnyard Runoff Control	$112,506	81,740	10,348	12,489
Capture and Reuse	$173,816	14,769	4,606	0
Conservation Plans	$236,227	36,110	6,023	3,087,643
Conservation Tillage	$0	5,420	859	1,743,977
Continuous No Till Alone	$0	0	0	0
Continuous No-Till & Conservation Tillage	$0	0	0	0
Cover Crops	$0	0	0	0
Cropland Irrigation Management	$0	80,882	0	0
Dairy Precision Feeding and Forage Management	$0	5,999	1,037	0
Land Retirement	$1,114,689	192,804	15,186	464,015
Nutrient Management – N Target	$0	2,097	0	0
Nutrient Management – P Target	$0	0	543	0
Phytase - Poultry	$0	0	8,901	0
Phytase - Swine	$0	0	40	0
Prescribed Grazing	$0	0	0	0
Water Control Structures	$1,858,850	463,263	0	0
Totals: Cost-Effective BMP Implementation	**$3,496,088**	**883,084**	**47,543**	**5,308,124**
	Estimated WIP Cost ($/yr)	**TMDL N Reduction Target (lbs/yr)**	**TMDL P Reduction Target (lbs/yr)**	**TMDL TSS Reduction Target (lbs/yr)**
WIP/CBM TMDL Data	**$19,399,653**	**870,449**	**44,432**	**-9,439,601**

*practices highlighted in red were excluded due to elimination of high MAC BMP implementations

Table A.10 – Maryland Cost-Effective BMP Portfolio: Land Retirement Scenario

BMP	Total Cost ($/yr)	N Load Reductions (lbs/yr)	P Load Reductions (lbs/yr)	TSS Load Reductions (lbs/yr)
Ammonia Emissions Reduction – Biofilters*	$0	0	0	0
AWMS- Livestock	$0	0	0	0
AWMS – Poultry	$0	0	0	0
Barnyard Runoff Control	$14,568	8,391	1,082	3,929
Capture and Reuse	$601,180	141,899	23,533	0
Conservation Plans	$323,325	83,580	8,726	7,938,463
Conservation Tillage	$0	31,127	2,805	6,528,243
Continuous No Till Alone	$0	237,961	36,288	50,736,911
Continuous No-Till & Conservation Tillage	$0	48,980	6,725	15,615,474
Cover Crops	$325,395	63,508	30	39,409
Cropland Irrigation Management	$0	279,380	0	0
Dairy Precision Feeding and Forage Management	$0	19,341	2,837	0
Enhanced Nutrient Management – N Target	$0	0	0	0
Land Retirement	$6,020,529	1,359,978	61,671	14,403,152
Nutrient Management – N Target	$24,826	5,408	0	0
Phytase - Poultry	$0	0	2,758	0
Phytase - Swine	$0	0	84	0
Prescribed Grazing	$0	0	0	0
Stream Access Control	$0	0	0	0
Water Control Structures	$5,582,655	1,284,773	0	0
Totals: Cost-Effective BMP Implementation	**$12,892,478**	**3,564,326**	**146,539**	**95,265,581**
	Estimated WIP Cost ($/yr)	**TMDL N Reduction Target (lbs/yr)**	**TMDL P Reduction Target (lbs/yr)**	**TMDL TSS Reduction Target (lbs/yr)**
WIP/CBM TMDL Data	**$82,987,333**	**3,559,095**	**83,009**	**-131,929,541**

*practices highlighted in red were excluded due to elimination of high MAC BMP implementations

Table A.11 – New York Cost-Effective BMP Portfolio: Land Retirement Scenario

BMP	Total Cost ($/yr)	N Load Reductions (lbs/yr)	P Load Reductions (lbs/yr)	TSS Load Reductions (lbs/yr)
Ammonia Emissions Reduction – Biofilters*	$0	0	0	0
Animal Waste Management Systems - Livestock	$0	0	0	0
Animal Waste Management Systems - Poultry	$0	0	0	0
Barnyard Runoff Control	$93,624	10,447	1,739	26,058
Capture and Reuse	$632,769	48,936	16,141	0
Conservation Plans	$724,128	60,445	8,185	3,089,926
Conservation Tillage	$0	13,455	2,899	1,280,417
Continuous No Till Alone	$0	10,339	1,543	779,086
Continuous No-Till & Conservation Tillage	$0	208,653	29,623	20,872,714
Cover Crops	$1,719,952	136,260	709	343,195
Dairy Precision Feeding and Forage Management	$0	29,277	5,400	0
Enhanced Nutrient Management – N Target	$0	0	0	0
Land Retirement	$6,739,377	621,554	41,420	6,520,260
Nutrient Management – N Target	$0	0	0	0
Nutrient Management – P Target	$193,559	0	1,953	0
Phytase - Poultry	$0	0	62	0
Phytase - Swine	$0	0	64	0
Prescribed Grazing	$7,124	444	44	677
Stream Access Control	$0	0	0	0
Totals: Cost-Effective BMP Implementation	**$10,110,533**	**1,139,810**	**109,782**	**32,912,333**
	Estimated WIP Cost ($/yr)	**TMDL N Reduction Target (lbs/yr)**	**TMDL P Reduction Target (lbs/yr)**	**TMDL TSS Reduction Target (lbs/yr)**
WIP/CBM TMDL Data	**$71,185,343**	**1,095,424**	**108,885**	**18,313,970**

*practices highlighted in red were excluded due to elimination of high MAC BMP implementations

Table A.12 – Pennsylvania Cost-Effective BMP Portfolio: Land Retirement Scenario

BMP	Total Cost ($/yr)	N Load Reductions (lbs/yr)	P Load Reductions (lbs/yr)	TSS Load Reductions (lbs/yr)
Ammonia Emissions Reduction - Biofilters	$17,605,482	881,648	0	0
AWMS – Livestock*	$0	0	0	0
AWMS - Poultry	$23,049	705	98	0
Barnyard Runoff Control	$2,782,554	482,128	51,424	3,805,737
Capture and Reuse	$8,925,278	1,520,749	230,542	0
Conservation Plans	$2,662,319	622,912	43,589	39,724,456
Conservation Tillage	$0	310,101	8,933	48,659,143
Continuous No Till Alone	$0	788,192	58,009	81,319,388
Continuous No-Till & Conservation Tillage	$0	1,080,736	64,401	147,221,400
Cover Crops	$21,067,055	6,256,391	6,772	8,421,906
Dairy Precision Feeding and Forage Management	$0	282,544	38,308	0
Enhanced Nutrient Management – N Target	$2,098,544	226,902	0	0
Land Retirement	$39,705,362	10,817,756	308,537	162,264,737
Nutrient Management – N Target	$0	143,319	0	0
Nutrient Management – P Target	$0	0	36,791	0
Phytase - Poultry	$0	0	5,904	0
Phytase - Swine	$0	0	3,327	0
Prescribed Grazing	$4,016,313	251,596	28,592	9,385,850
Stream Access Control	$2,709,882	87,505	2,587	396,510
Totals: Cost-Effective BMP Implementation	**$101,595,838**	**23,753,184**	**887,814**	**501,199,127**
	Estimated WIP Cost ($/yr)	**TMDL N Reduction Target (lbs/yr)**	**TMDL P Reduction Target (lbs/yr)**	**TMDL TSS Reduction Target (lbs/yr)**
WIP/CBM TMDL Data	**$378,251,749**	**23,735,408**	**793,940**	**466,487,022**

*practices highlighted in red were excluded due to elimination of high MAC BMP implementations

Table A.13 – Virginia Cost-Effective BMP Portfolio: Land Retirement Scenario

BMP	Total Cost ($/yr)	N Load Reductions (lbs/yr)	P Load Reductions (lbs/yr)	TSS Load Reductions (lbs/yr)
Ammonia Emissions Reduction – Biofilters*	$0	0	0	0
AWMS – Livestock	$68,438,796	263,262	98,611	0
AWMS – Poultry	$4,664,407	80,223	30,850	0
Barnyard Runoff Control	$2,419,168	208,548	77,611	11,449,750
Capture and Reuse	$4,650,914	373,125	228,171	0
Conservation Plans	$2,774,359	290,960	108,649	94,120,482
Conservation Tillage	$0	21,438	6,912	4,123,045
Continuous No Till Alone	$0	225,199	86,793	98,006,382
Continuous No-Till & Conservation Tillage	$0	217,276	66,262	96,042,580
Cover Crops	$16,219,668	913,222	5,363	5,337,859
Cropland Irrigation Management	$0	188,690	0	0
Dairy Precision Feeding and Forage Management	$0	28,394	16,396	0
Enhanced Nutrient Management – N Target	$0	0	0	0
Land Retirement to FOR	$76,275,894	3,489,636	921,978	461,919,793
Nutrient Management – N Target	$0	0	0	0
Nutrient Management – P Target	$15,587,979	0	78,193	0
Phytase – Poultry	$0	0	30,246	0
Phytase – Swine	$0	0	1,518	0
Prescribed Grazing	$19,460,914	214,023	85,867	129,486,665
Stream Access Control	$12,523,612	24,239	10,300	8,370,353
Water Control Structures	$618,610	141,802	0	0
Totals: Cost-Effective BMP Implementation	**$223,634,321**	**6,680,037**	**1,853,720**	**908,856,909**
	Estimated WIP Cost ($/yr)	**TMDL N Reduction Target (lbs/yr)**	**TMDL P Reduction Target (lbs/yr)**	**TMDL TSS Reduction Target (lbs/yr)**
WIP/CBM TMDL Data	**$307,393,126**	**6,672,243**	**1,849,726**	**678,322,176**

*practices highlighted in red were excluded due to elimination of high MAC BMP implementations

Table A.14 – West Virginia Cost-Effective BMP Portfolio: Land Retirement Scenario

BMP	Total Cost ($/yr)	N Load Reductions (lbs/yr)	P Load Reductions (lbs/yr)	TSS Load Reductions (lbs/yr)
Ammonia Emissions Reduction – Biofilters*	$0	0	0	0
AWMS - Livestock	$0	0	0	0
AWMS- Poultry	$0	0	0	0
Barnyard Runoff Control	$172,406	4,799	3,264	615,122
Capture and Reuse	$0	0	0	0
Conservation Plans	$57,783	4,234	1,060	881,659
Conservation Tillage	$0	549	109	82,882
Continuous No Till Alone	$0	50,696	8,328	2,609,846
Continuous No-Till & Conservation Tillage	$0	23,173	11,811	2,463,529
Cover Crops	$2,543	100	3	9,160
Dairy Precision Feeding and Forage Management	$0	2,439	365	0
Enhanced Nutrient Management – N Target	$0	0	0	0
Land Retirement	$3,112,400	90,385	27,118	16,802,728
Nutrient Management – N Target	$0	0	0	0
Nutrient Management – P Target	$0	0	0	0
Phytase - Poultry	$0	0	1,085	0
Phytase - Swine	$0	0	4	0
Prescribed Grazing	$663,766	11,135	6,419	8,099,230
Stream Access Control	$1,965,284	1,942	1,706	5,702,086
Totals: Cost-Effective BMP Implementation	**$5,974,182**	**189,452**	**61,272**	**37,266,242**
	Estimated WIP Cost ($/yr)	**TMDL N Reduction Target (lbs/yr)**	**TMDL P Reduction Target (lbs/yr)**	**TMDL TSS Reduction Target (lbs/yr)**
WIP/CBM TMDL Data	**$43,946,274**	**176,741**	**52,527**	**34,724,975**

*practices highlighted in red were excluded due to elimination of high MAC BMP implementations

Appendix B: Figures

Scenario One MAC Curves

Figure B.1.

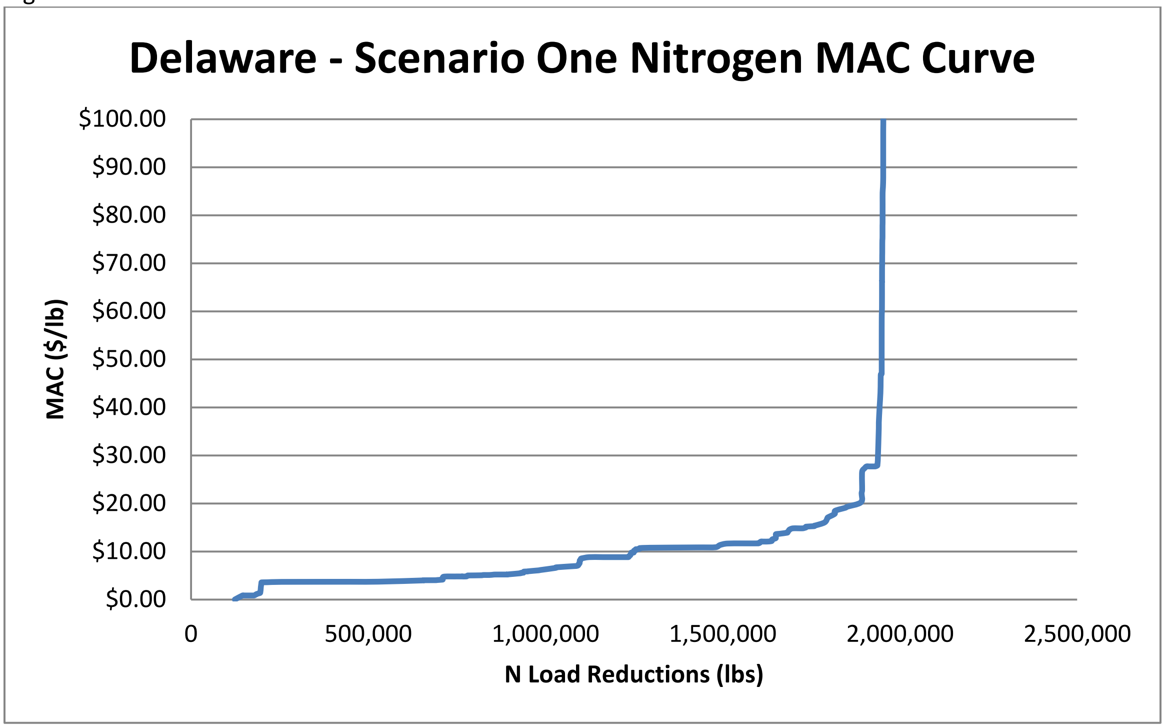


Figure B.2.

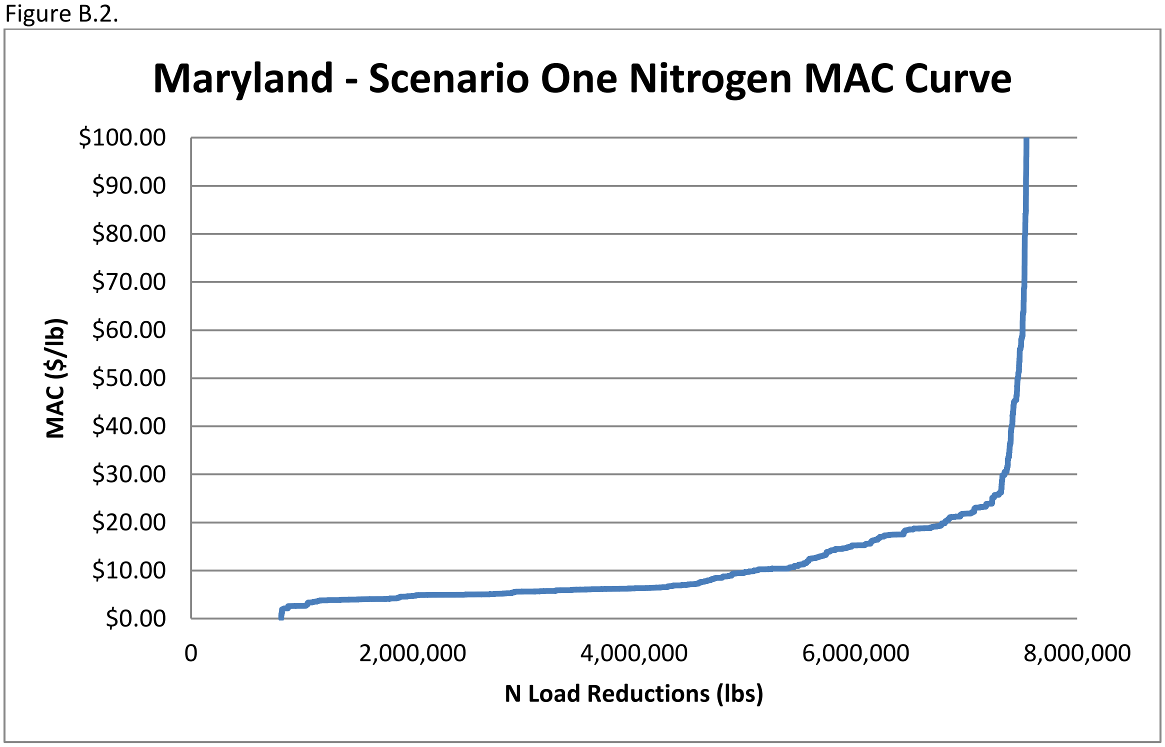


Figure B.3.

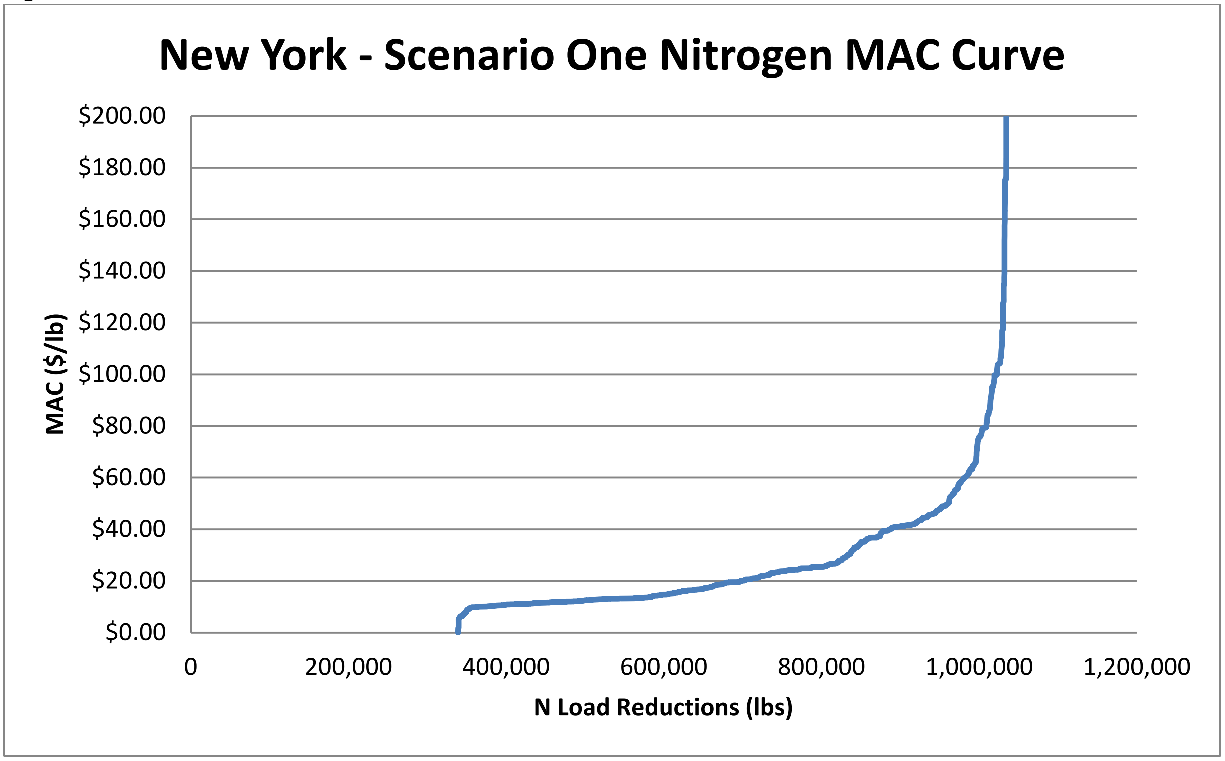


Figure B.4.

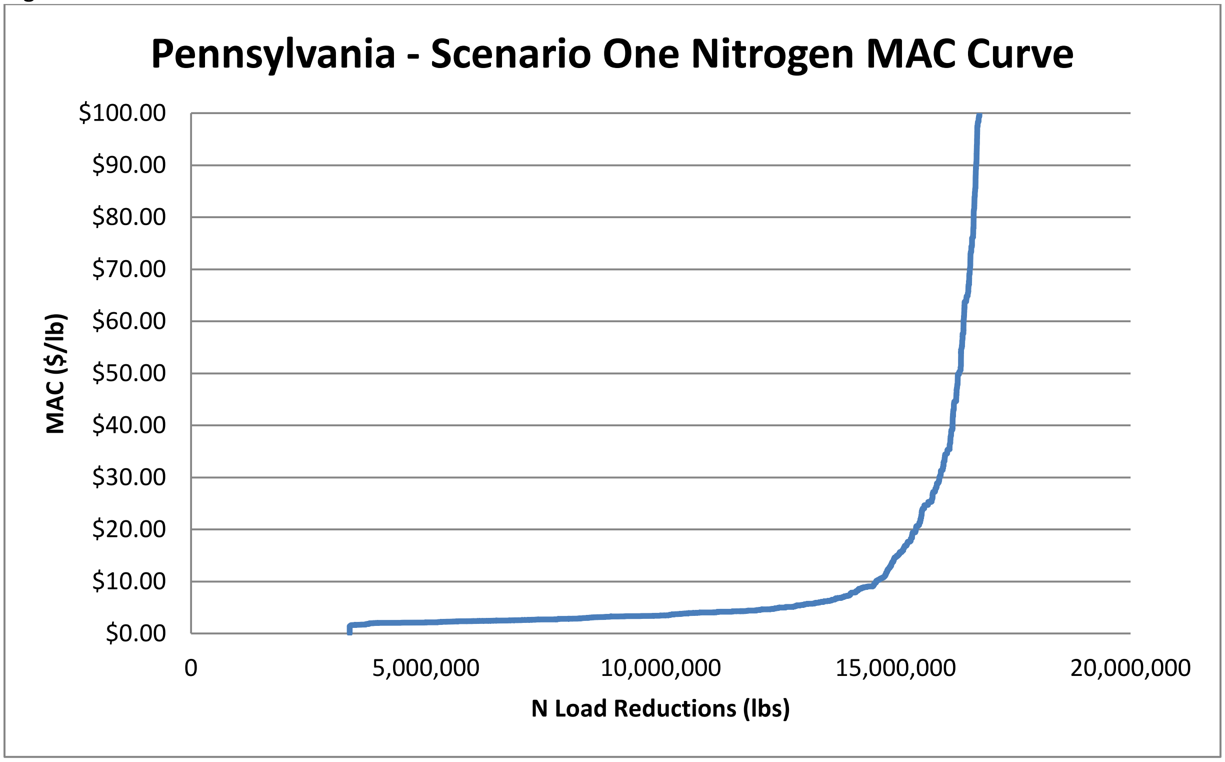
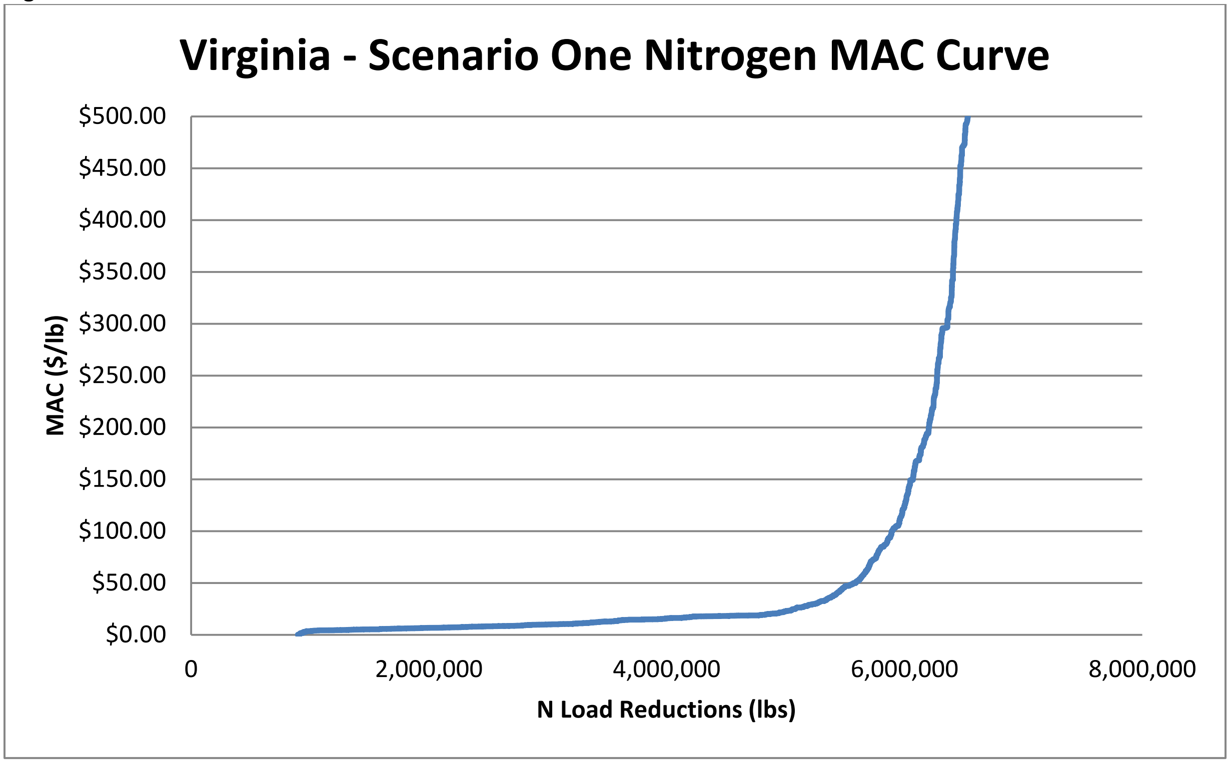


Figure B.5.



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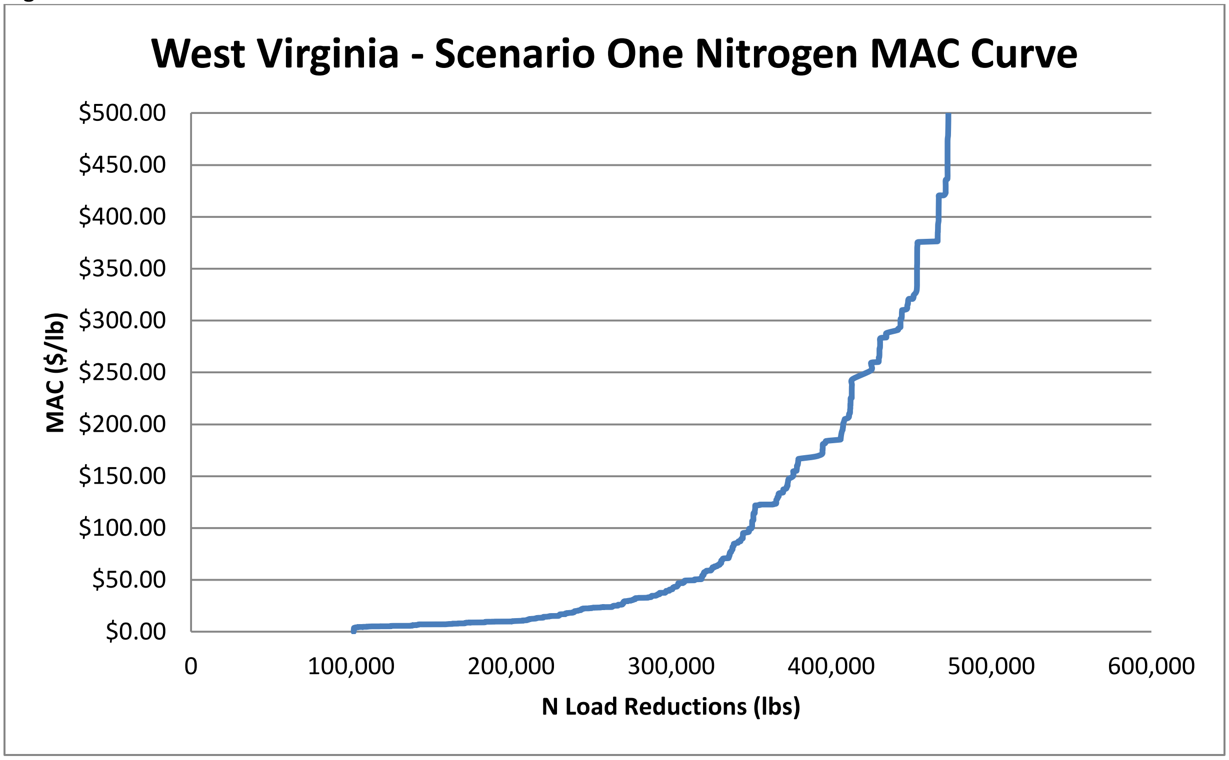

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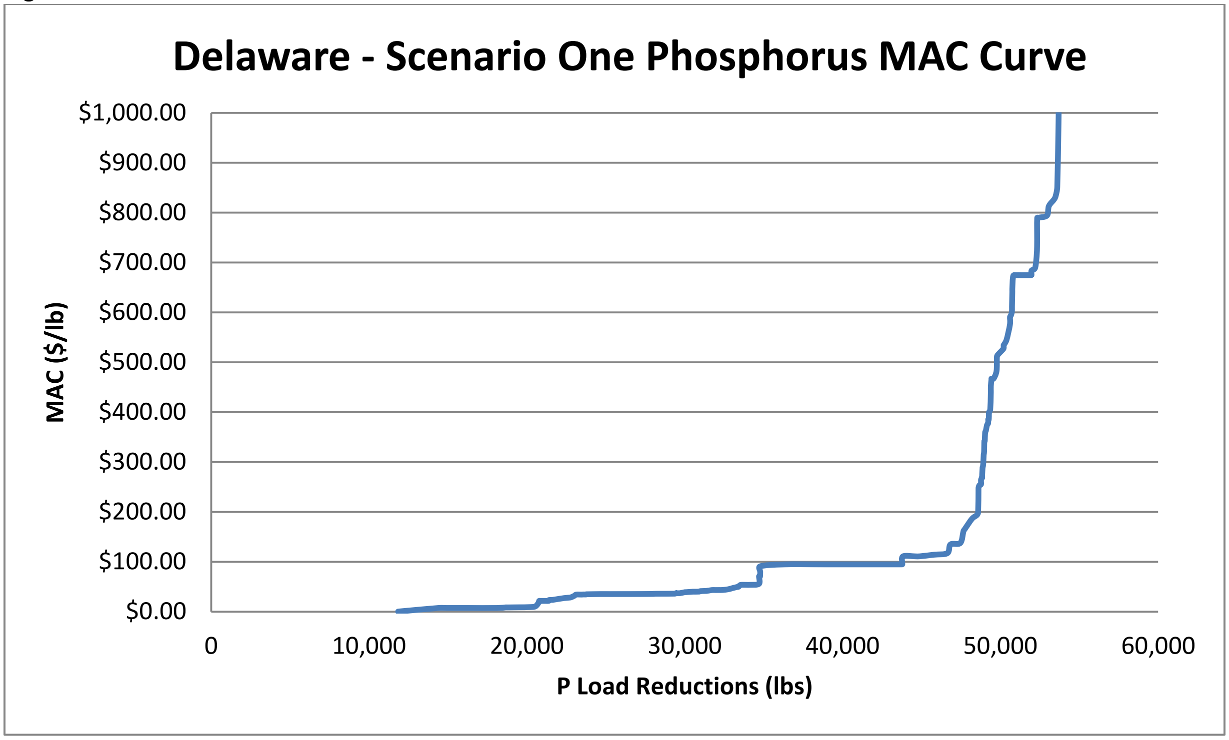

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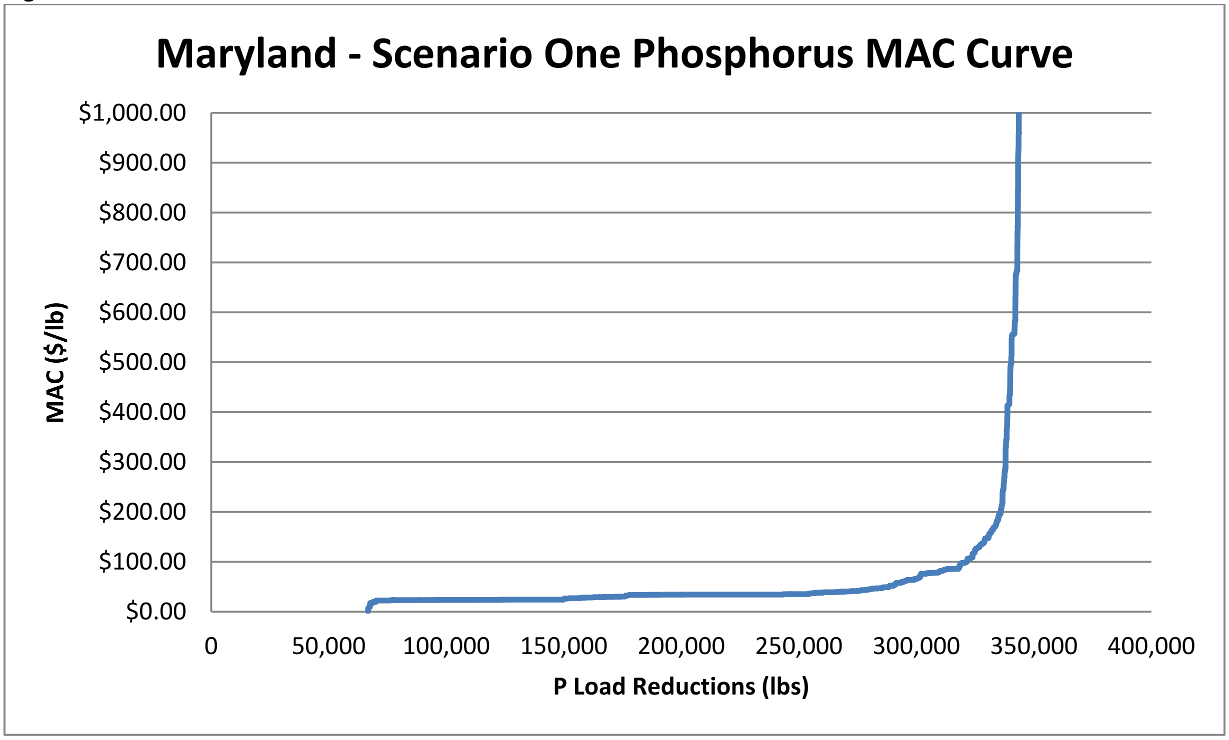

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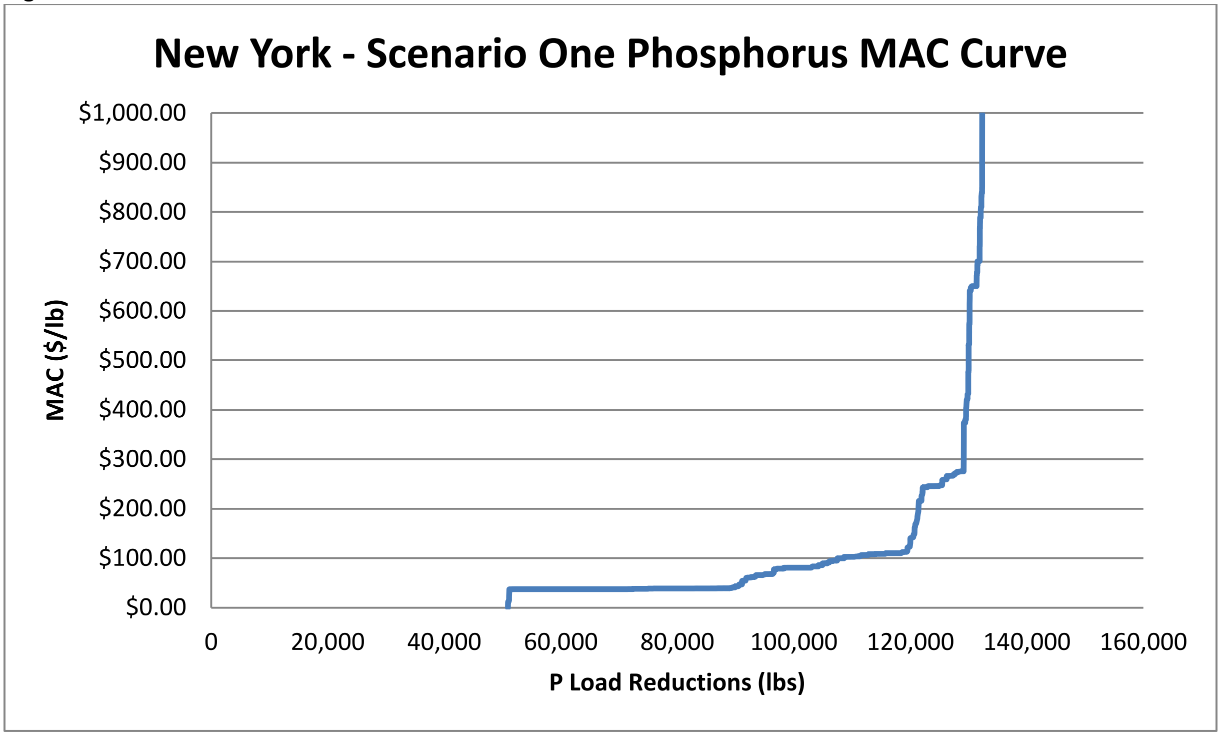

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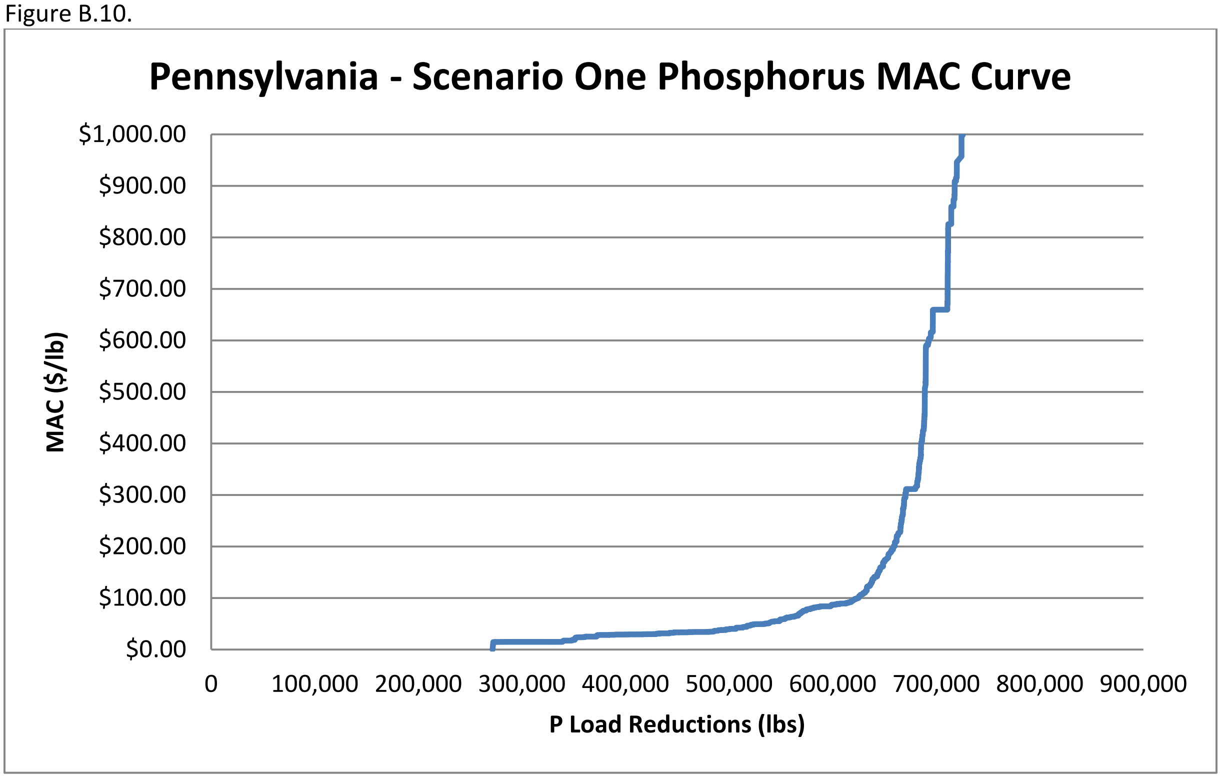

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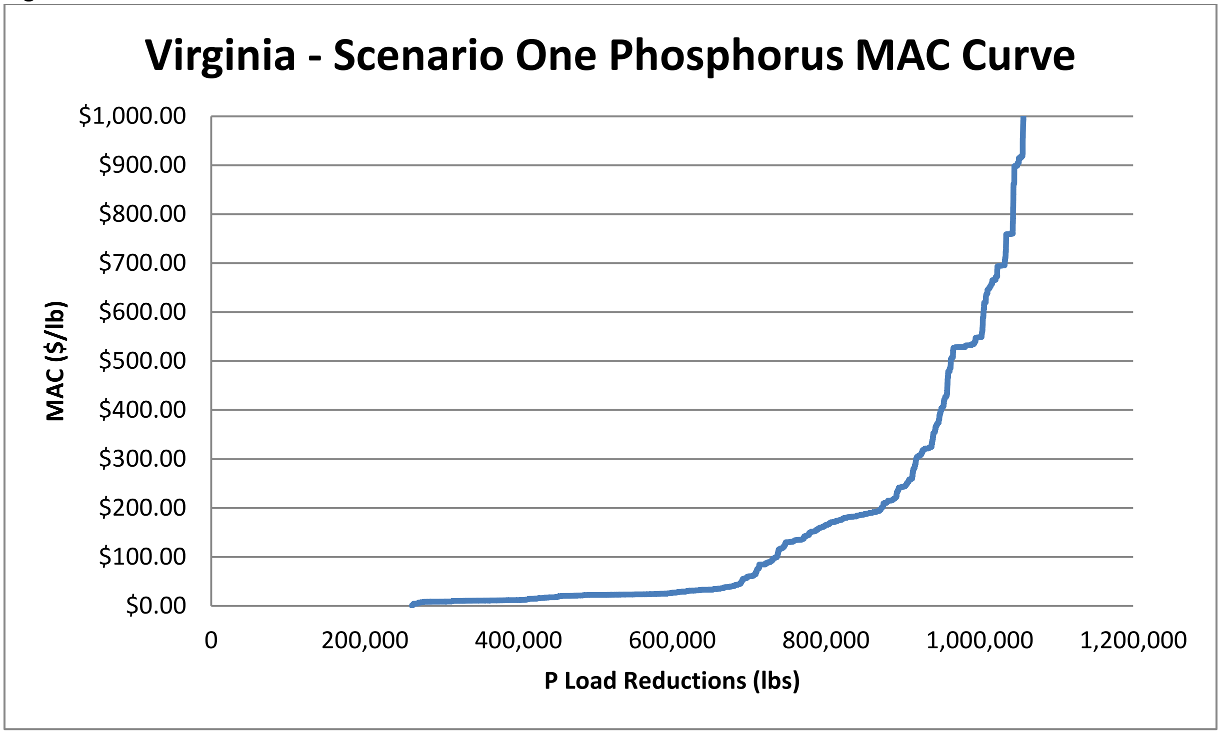

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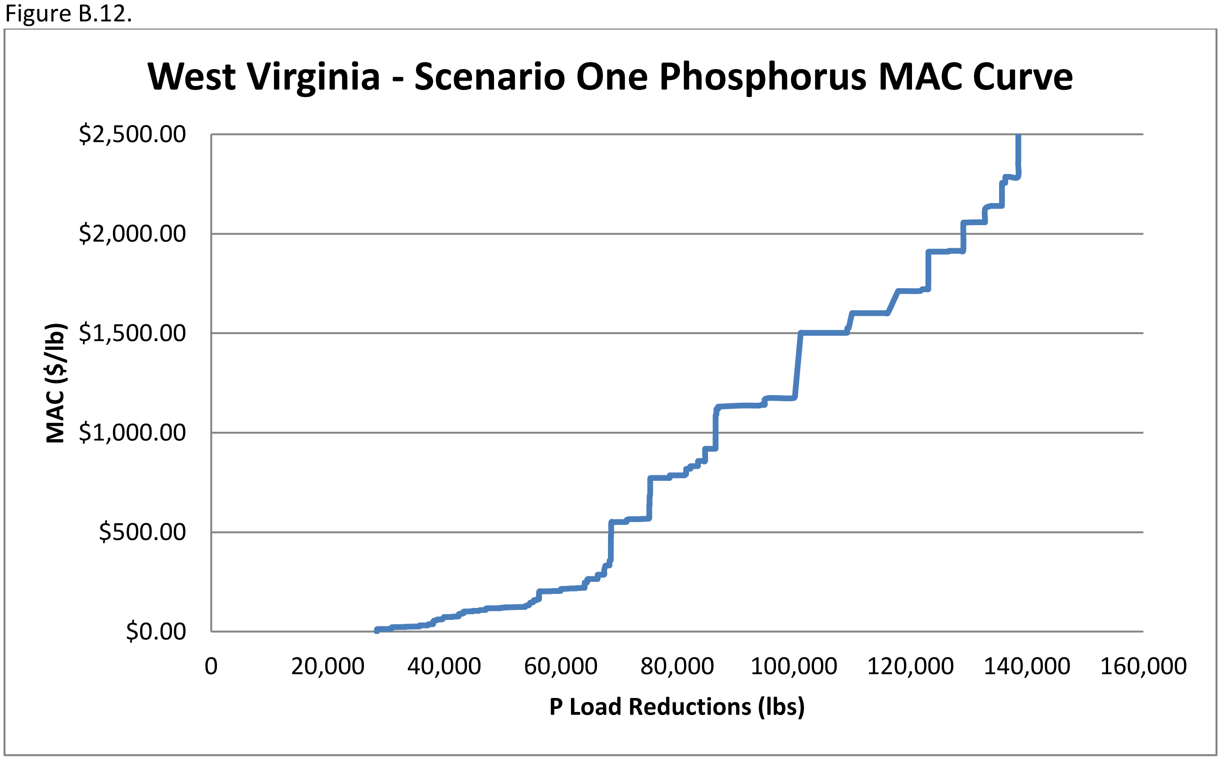

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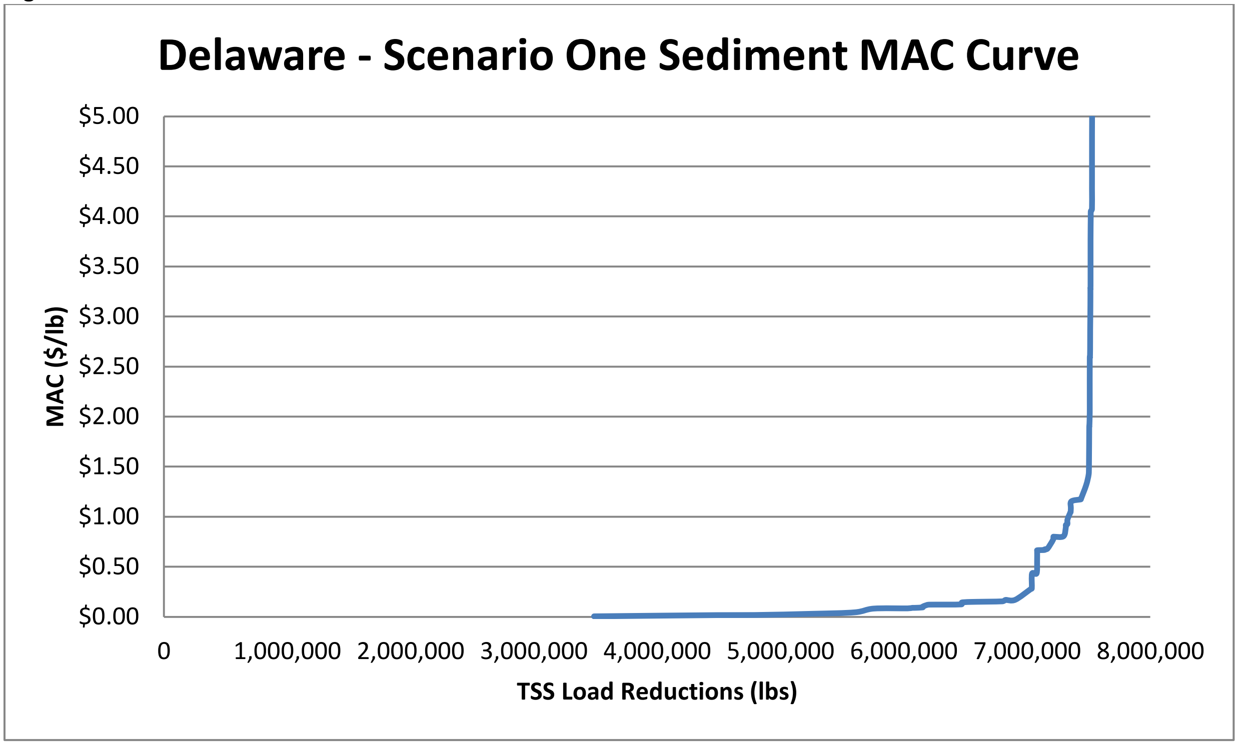

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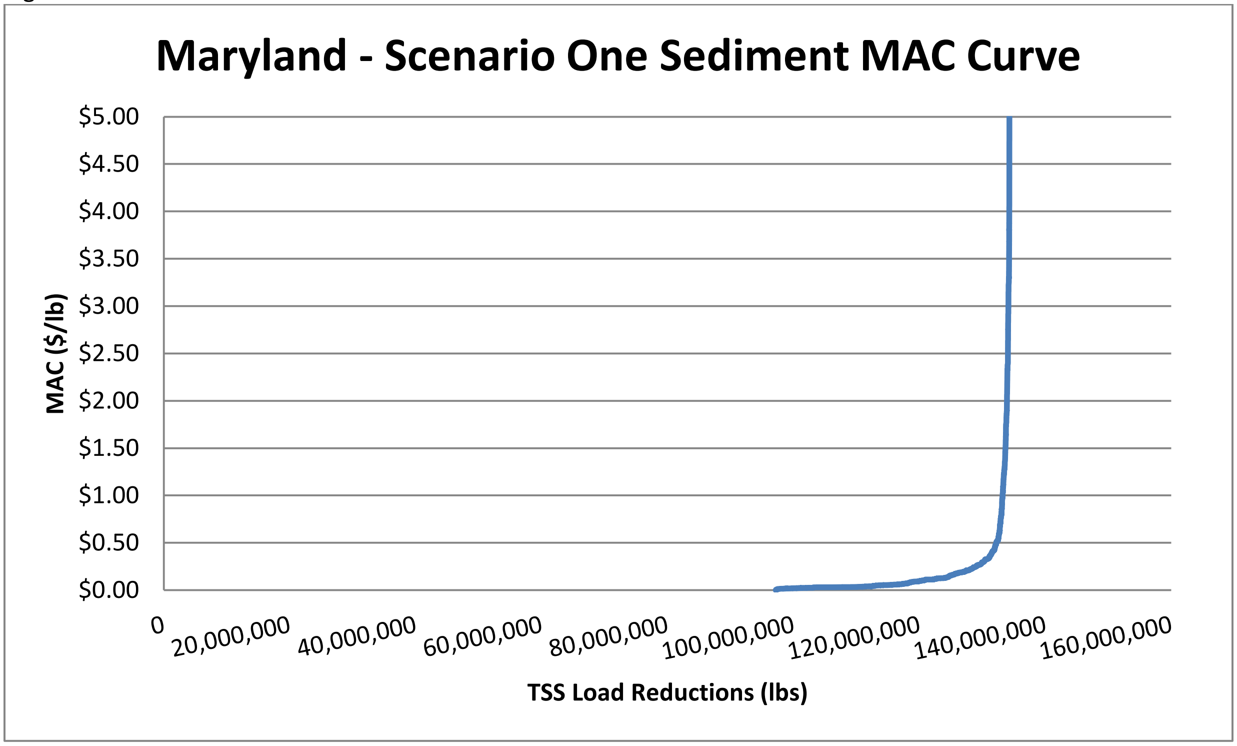

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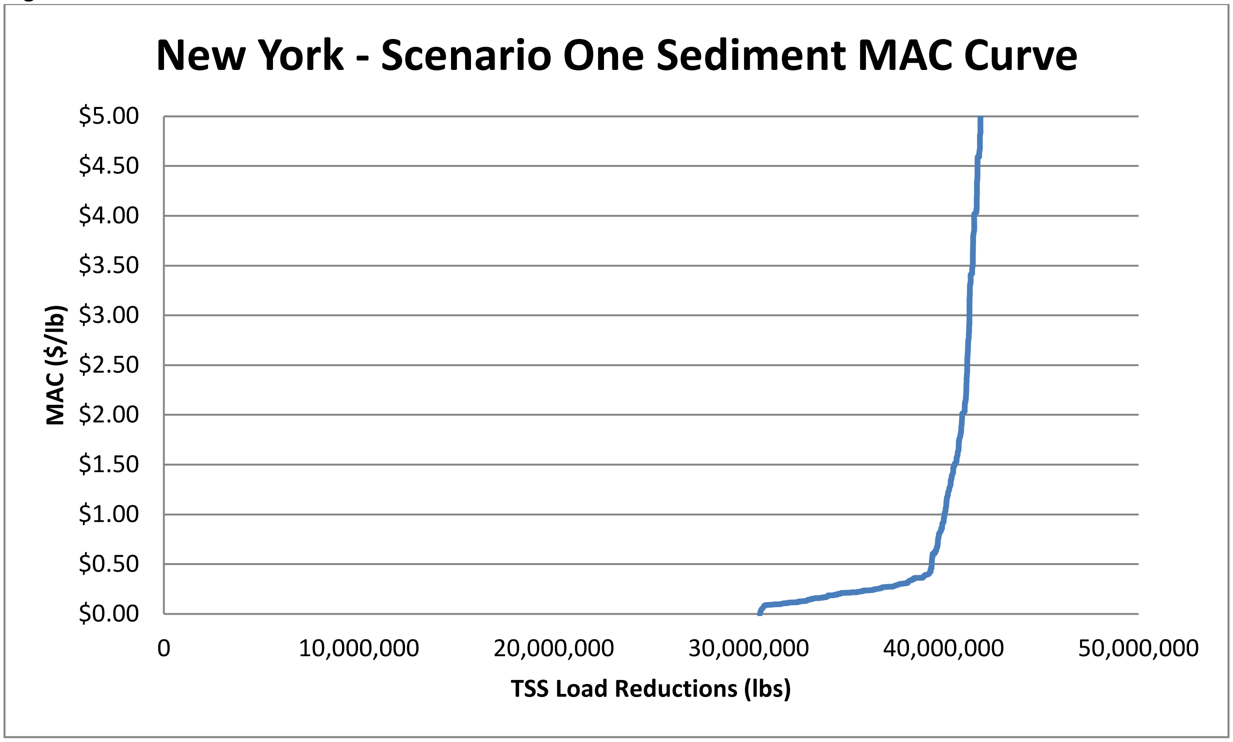

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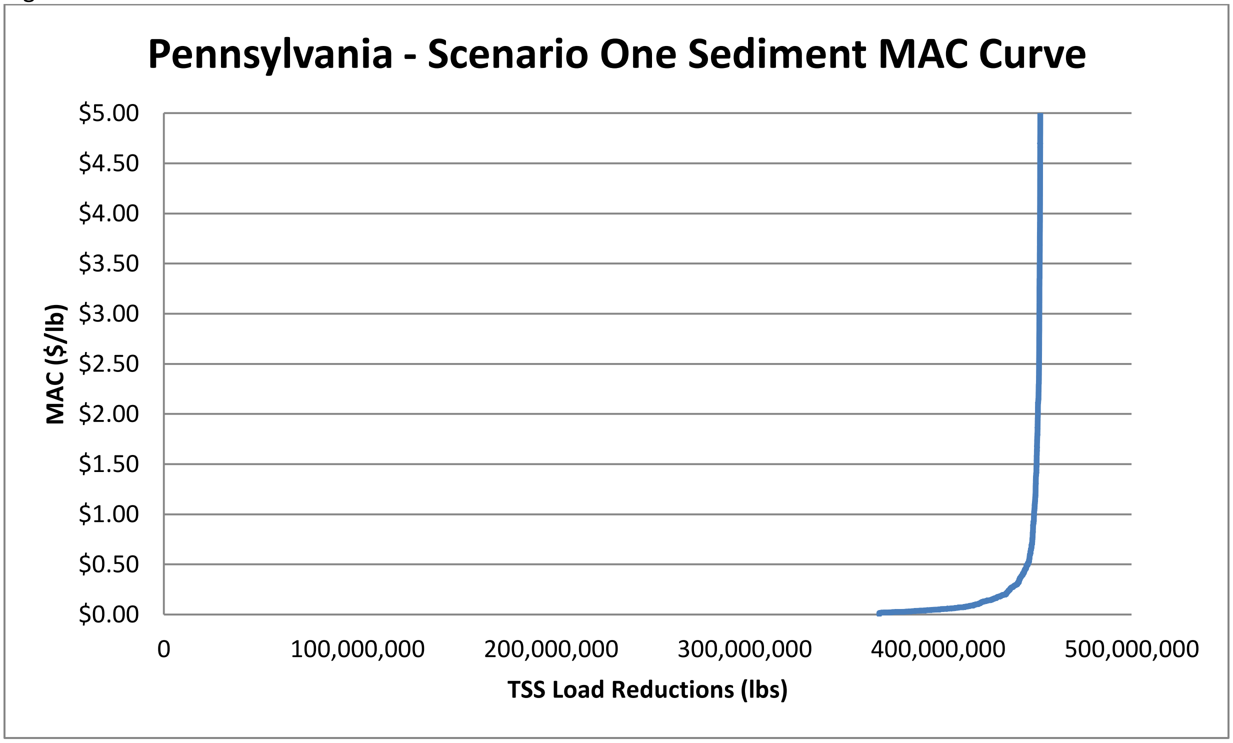

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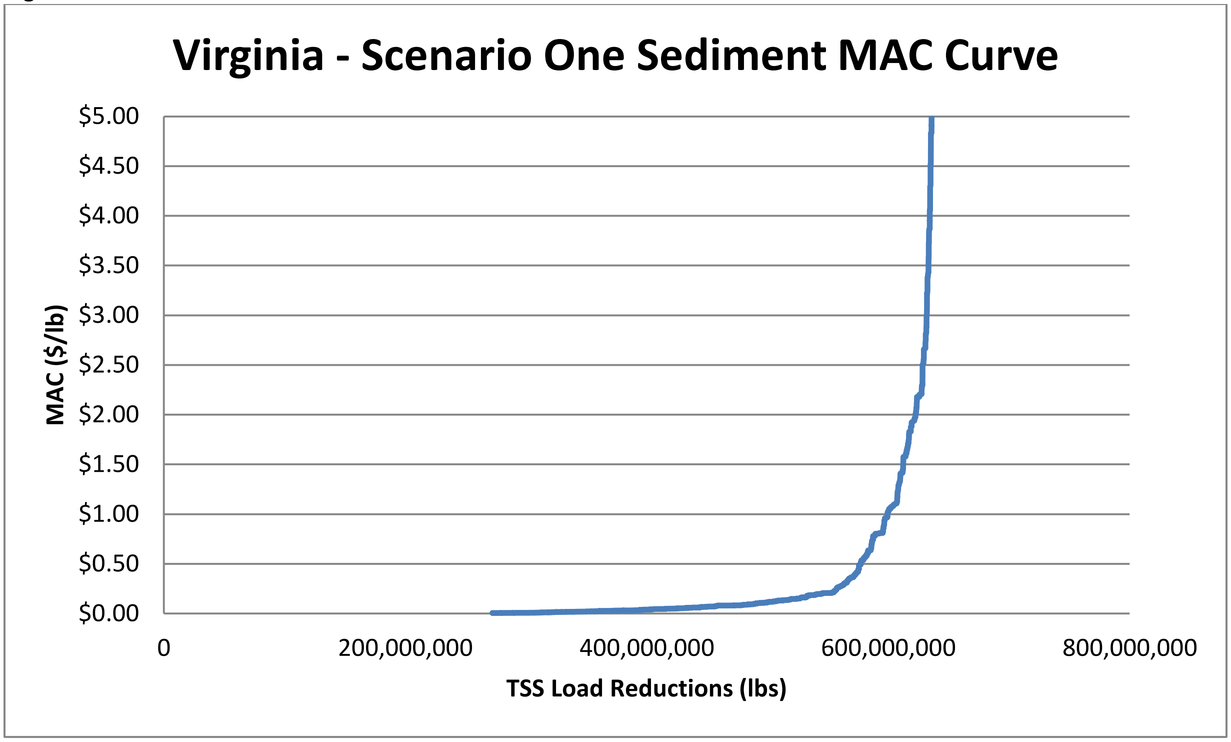

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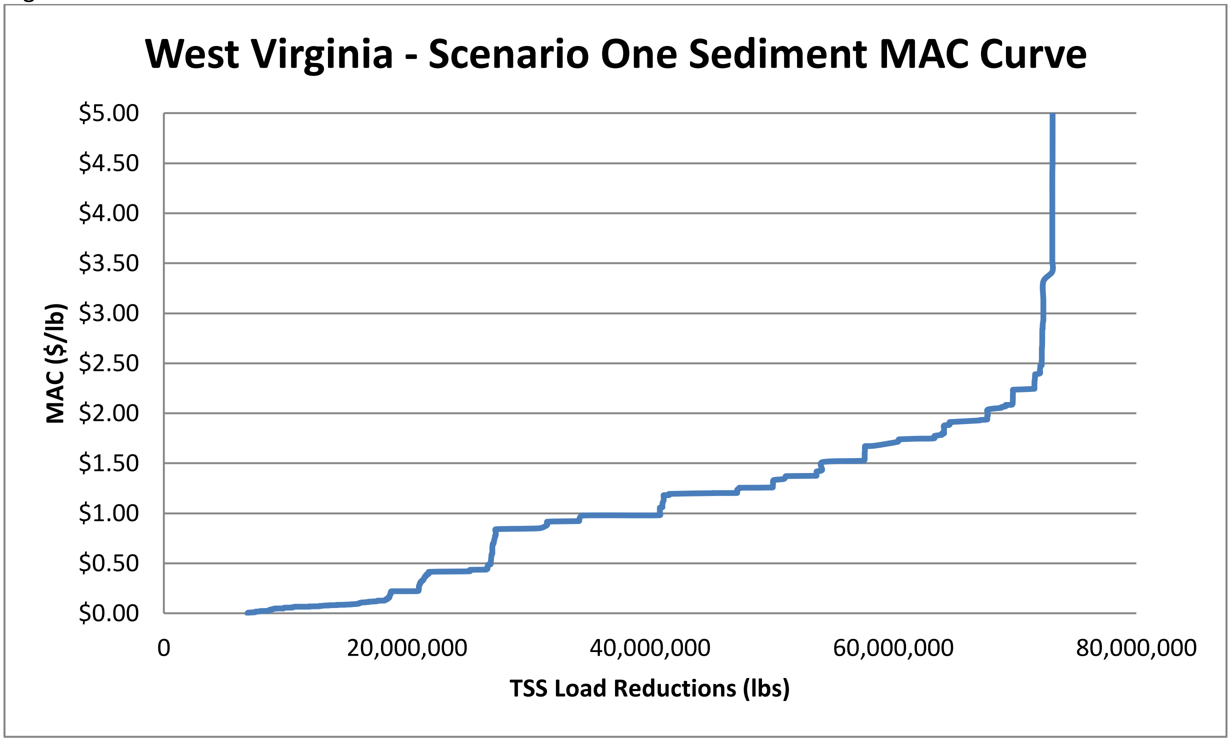

Scenario Two MAC Curves

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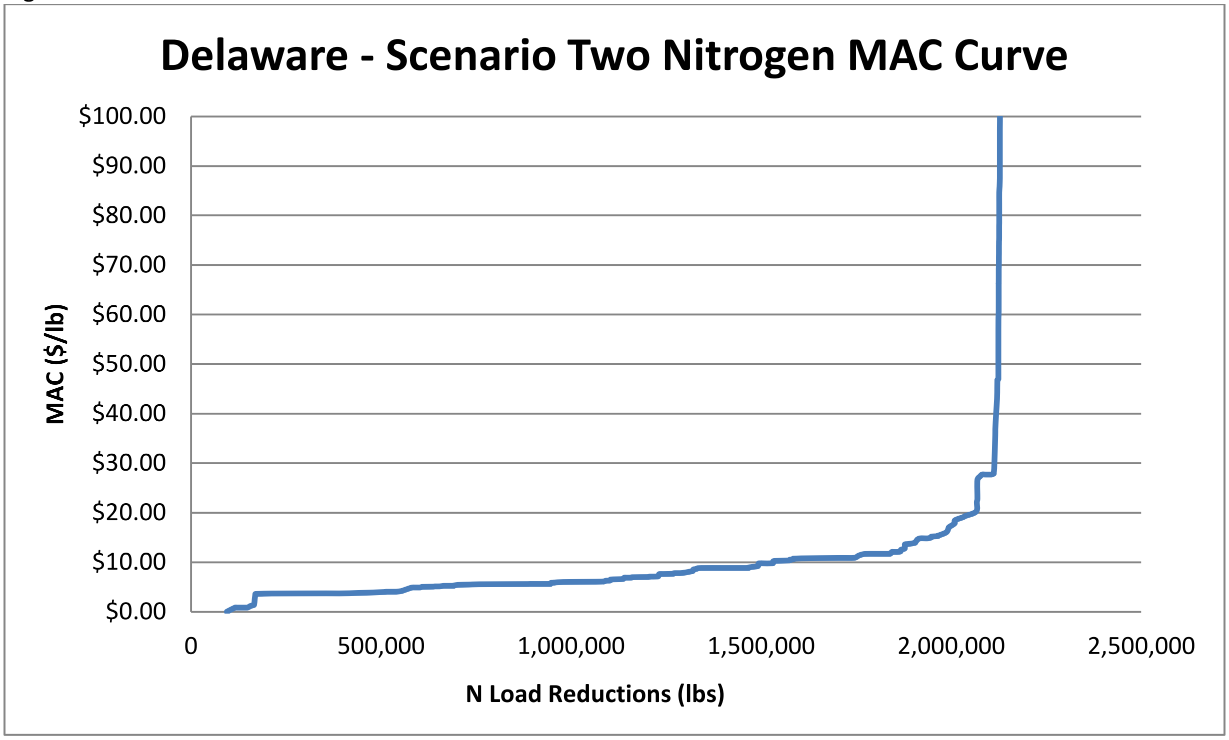

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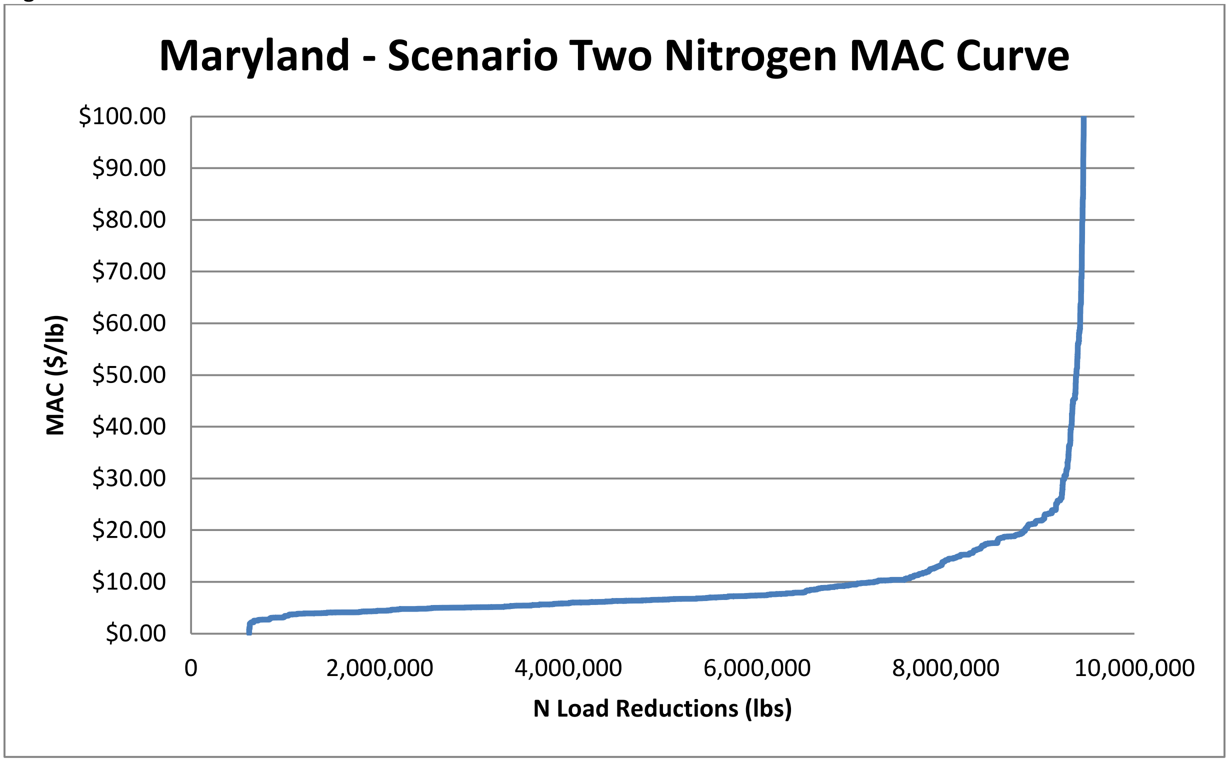

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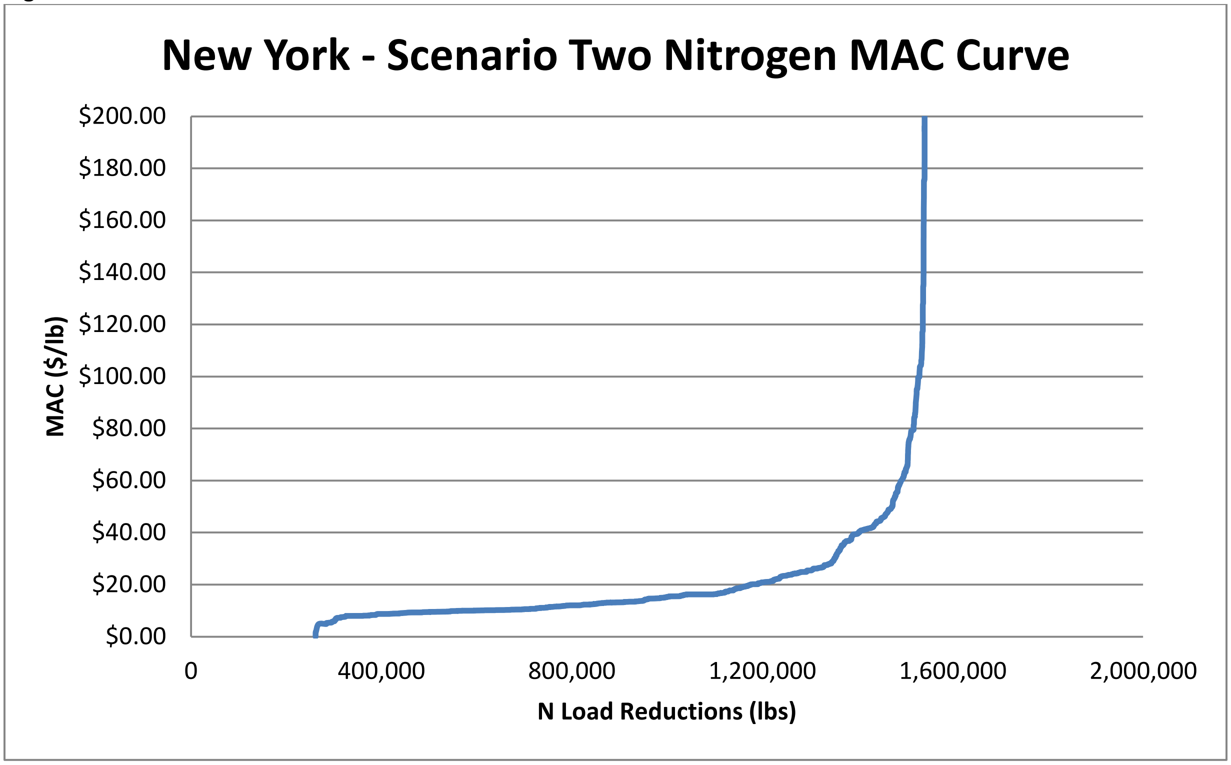

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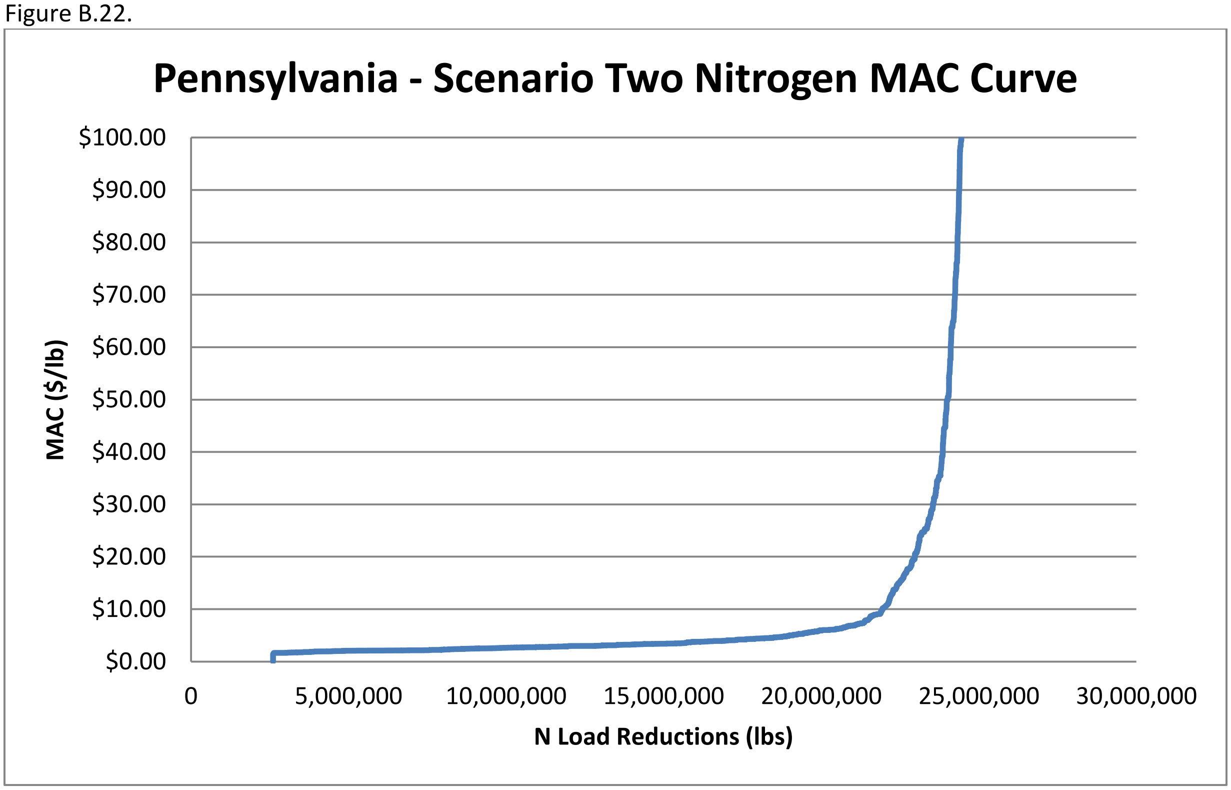

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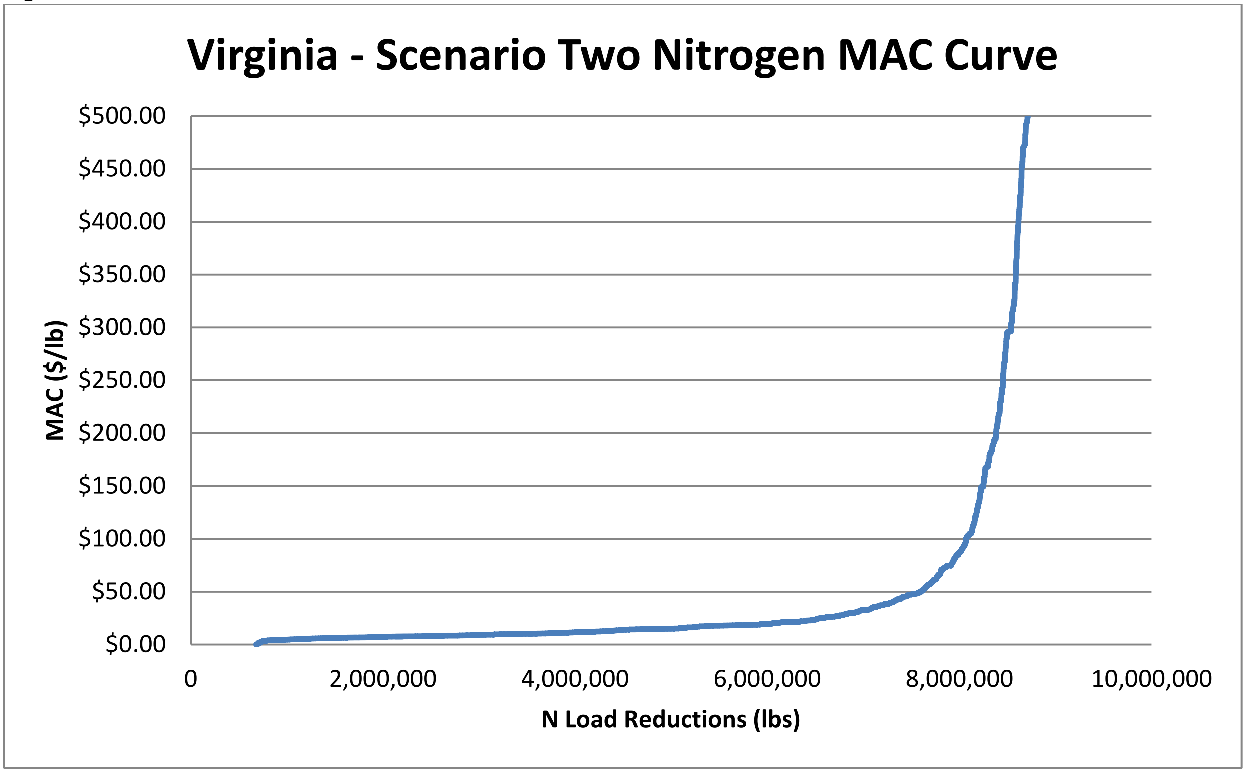

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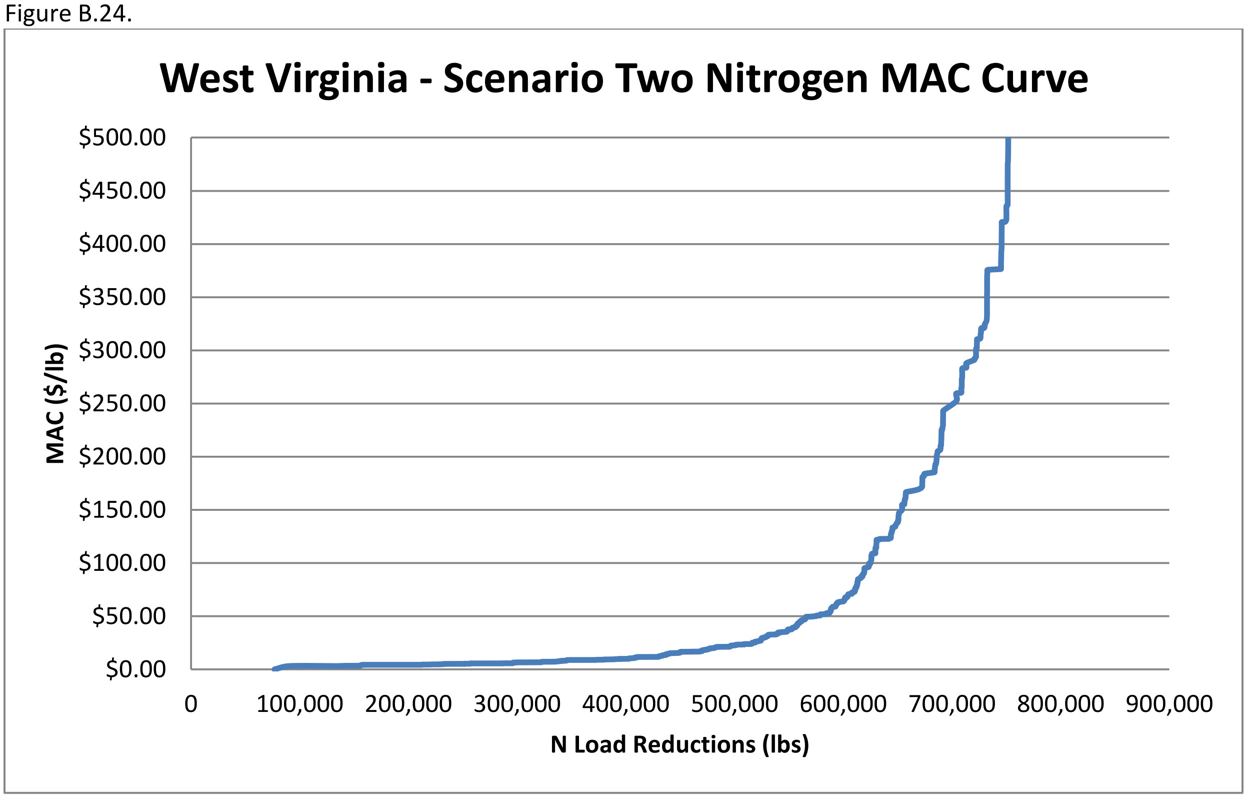

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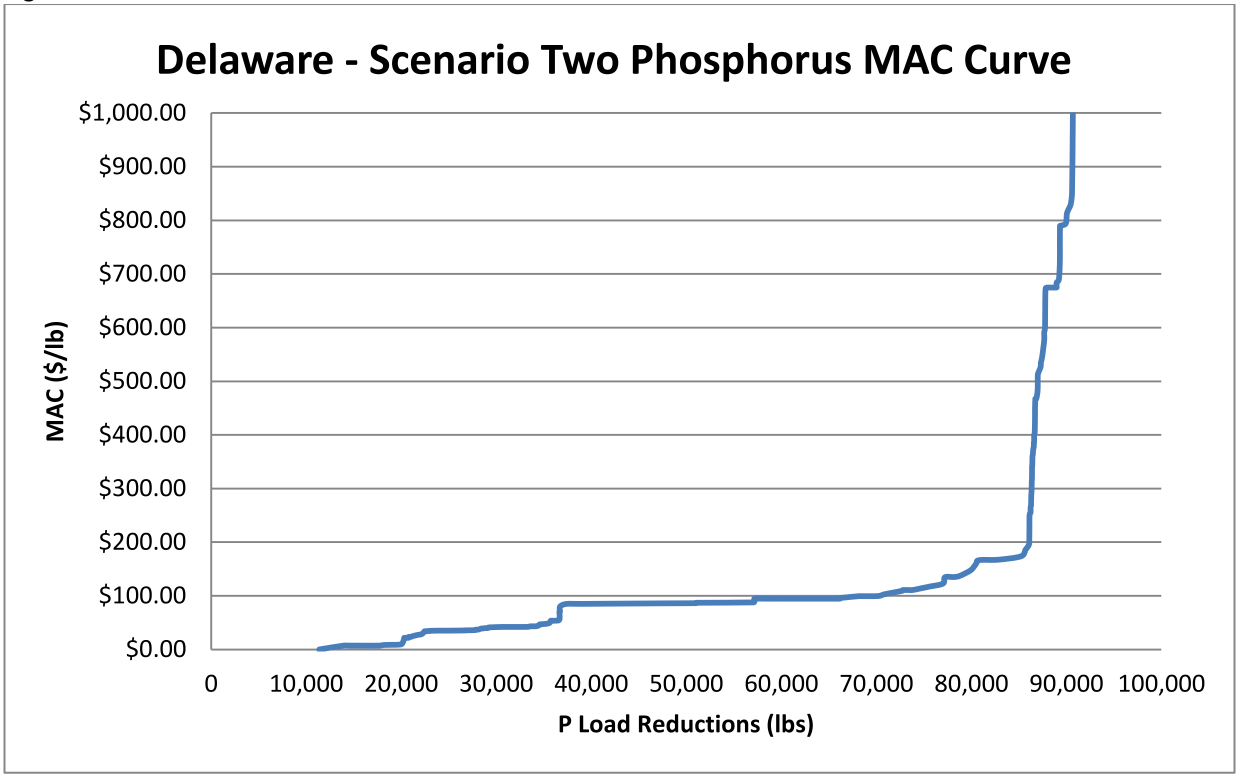

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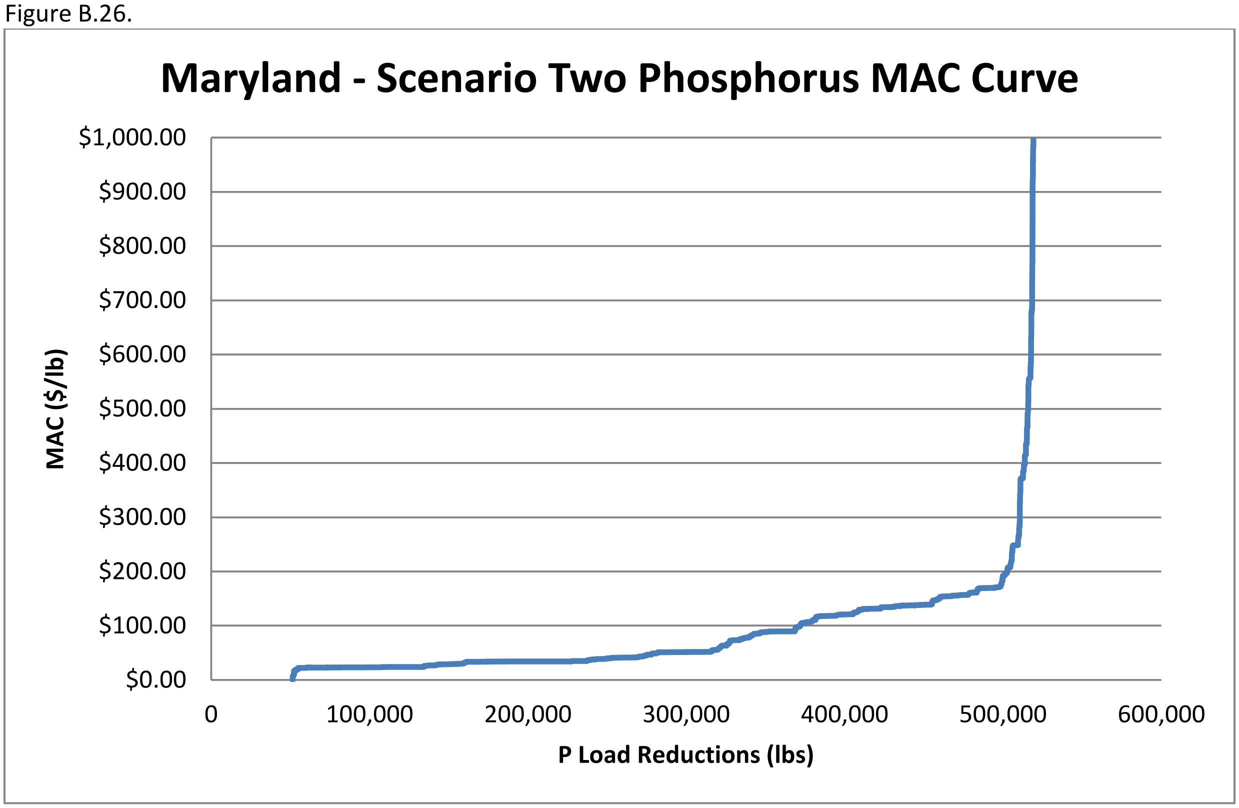

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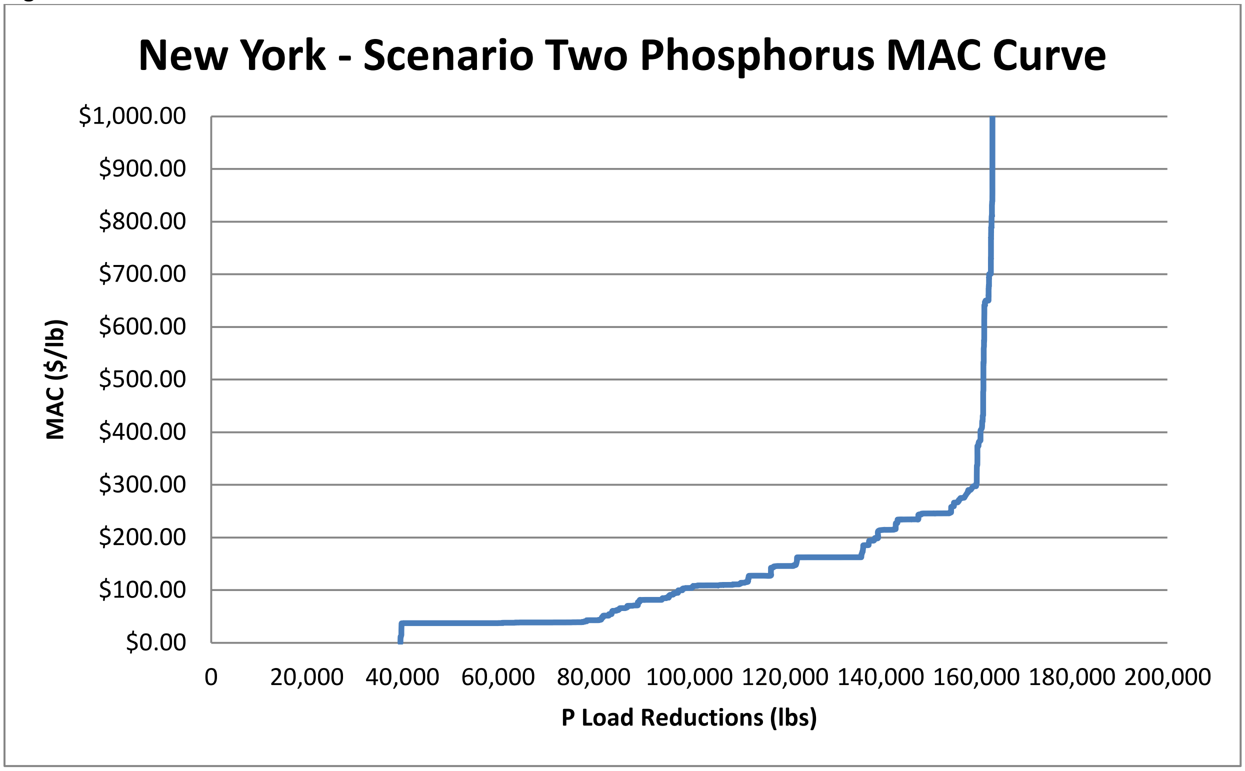

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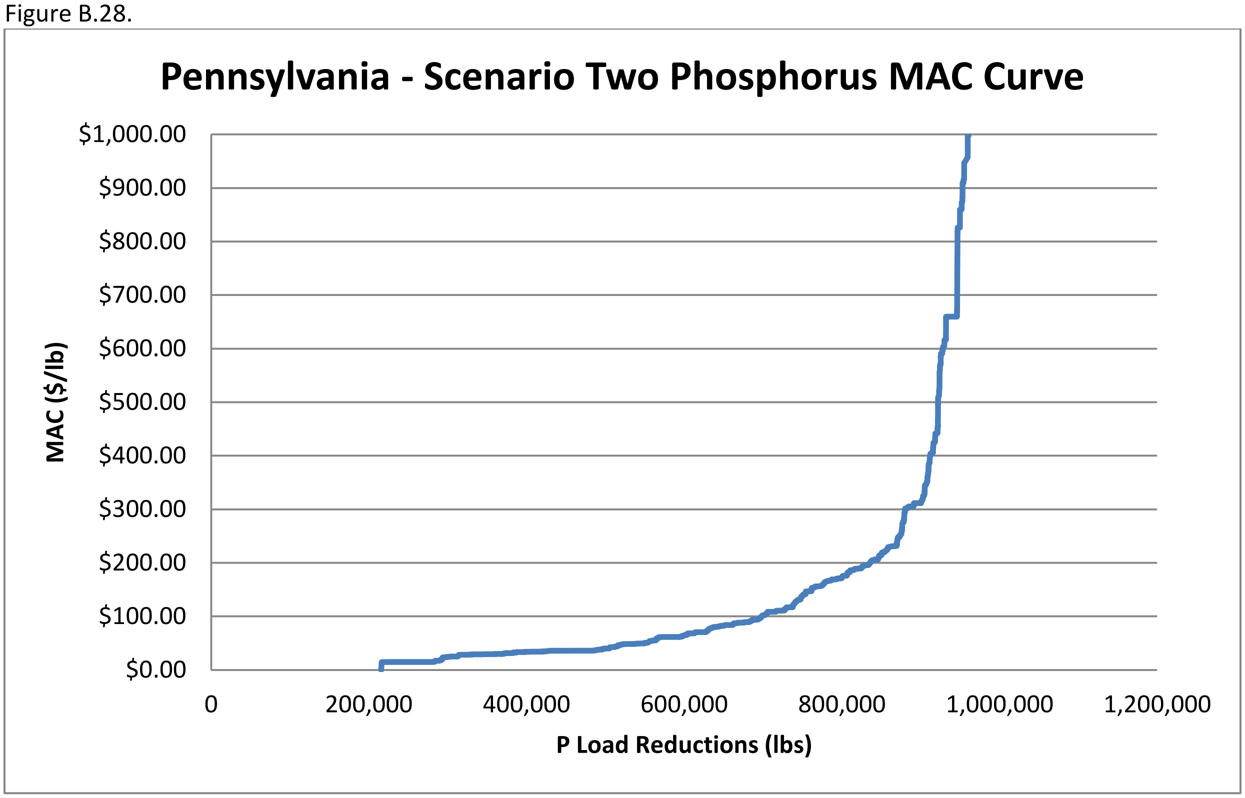

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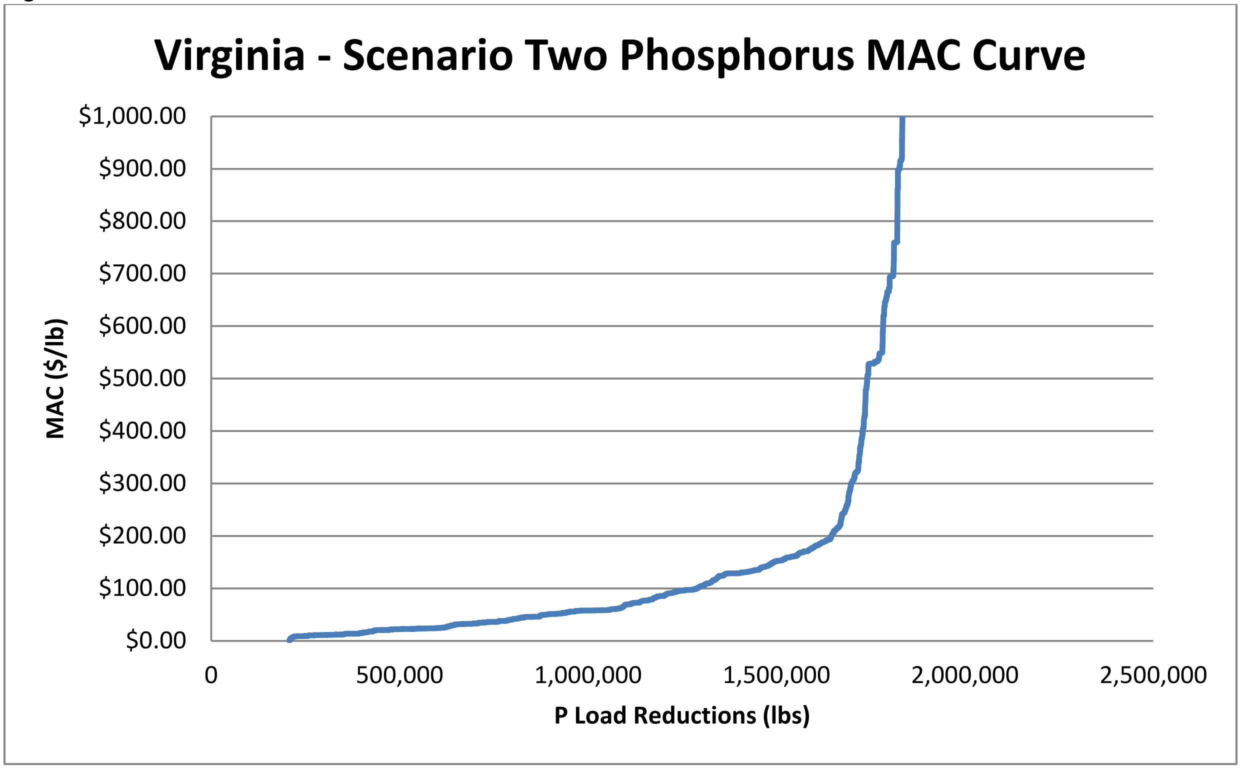

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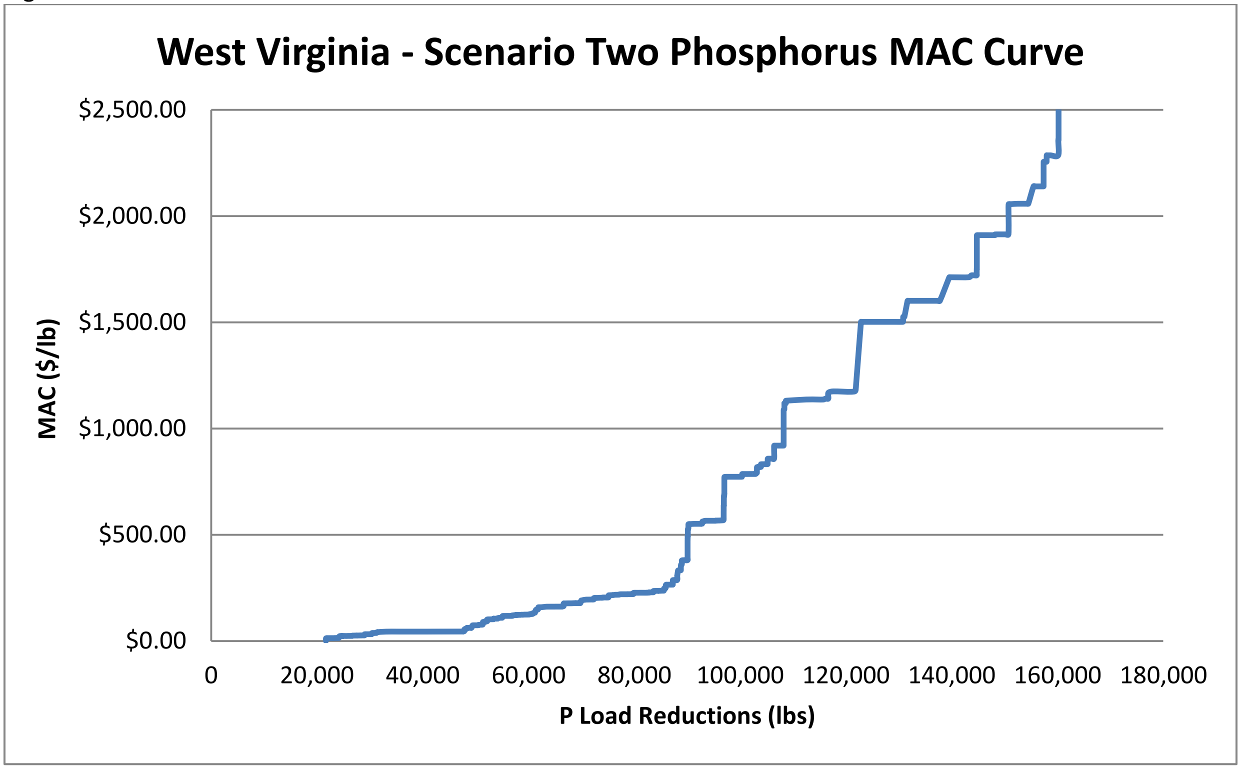

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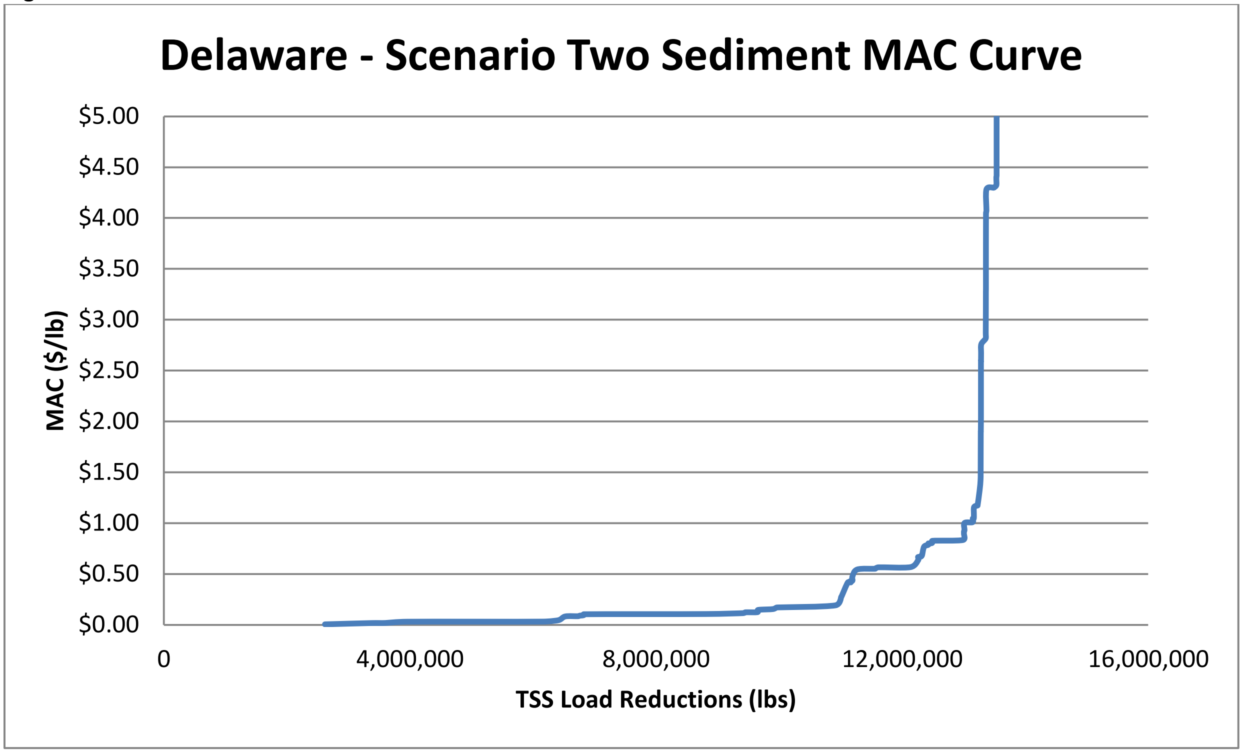

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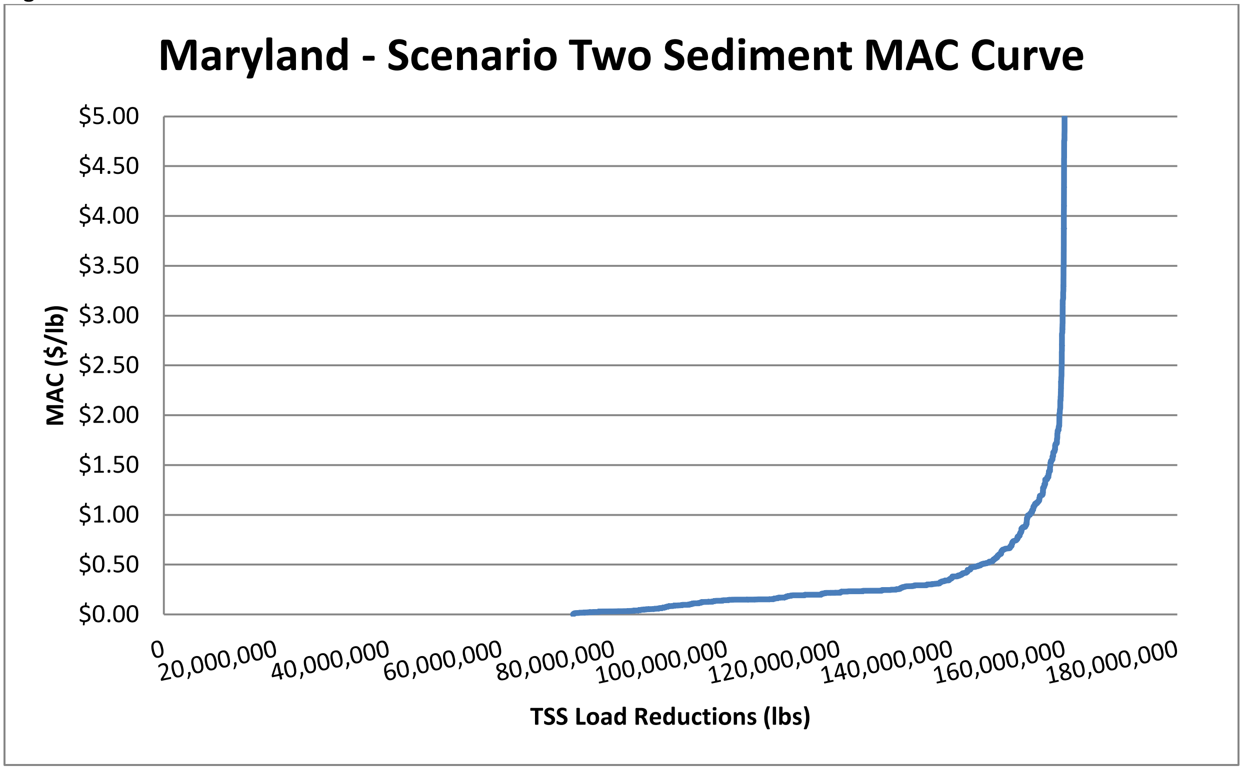

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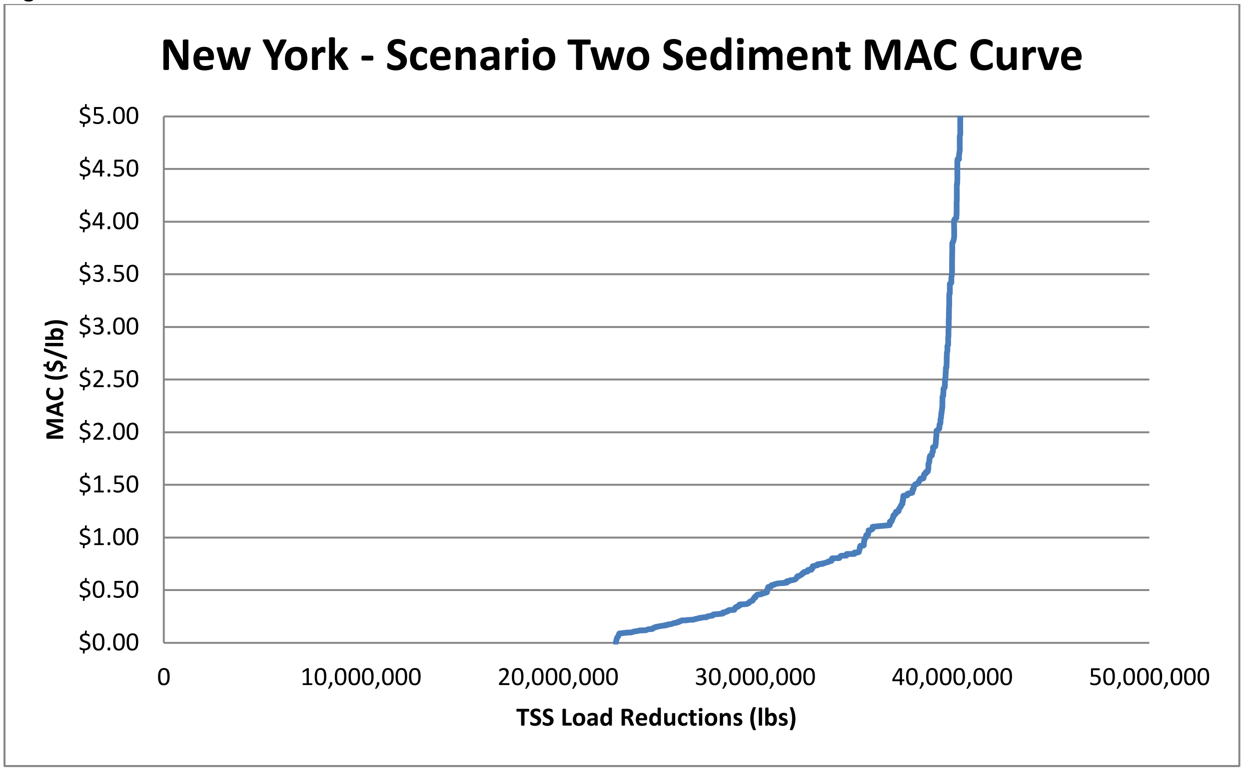

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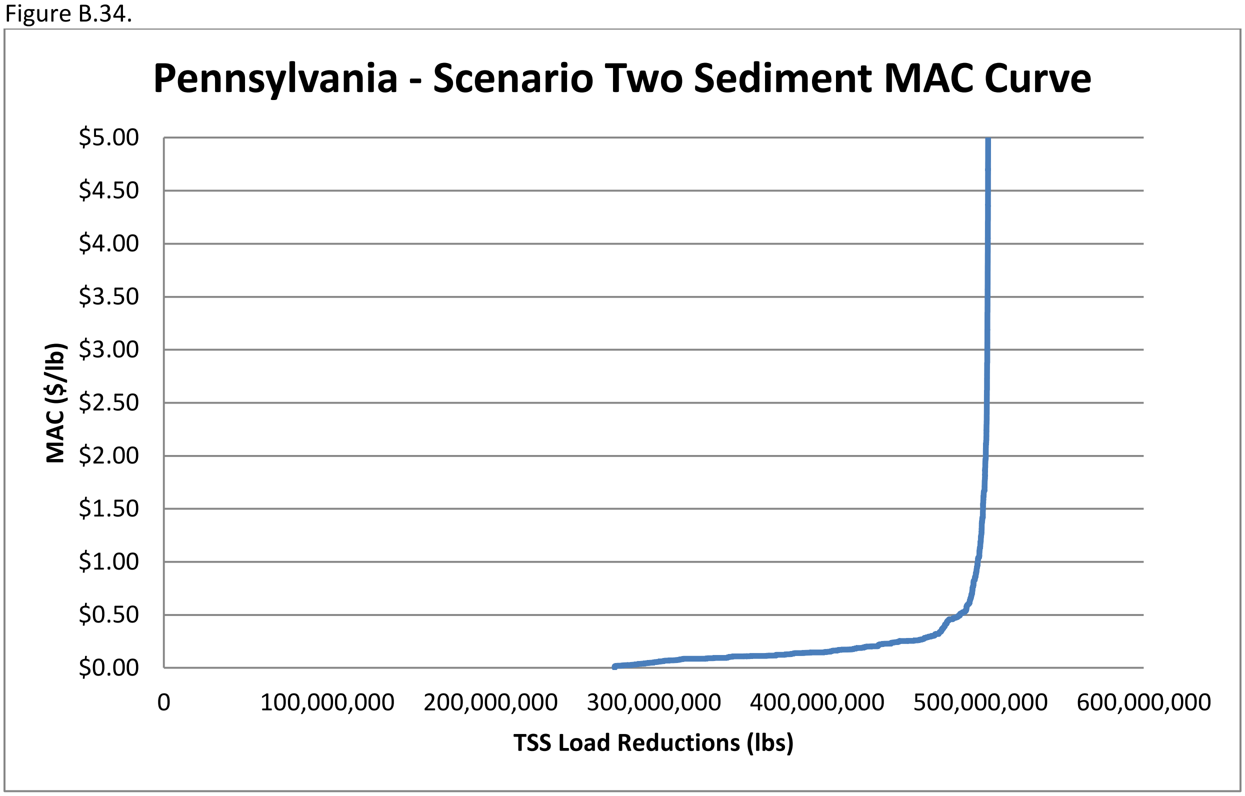

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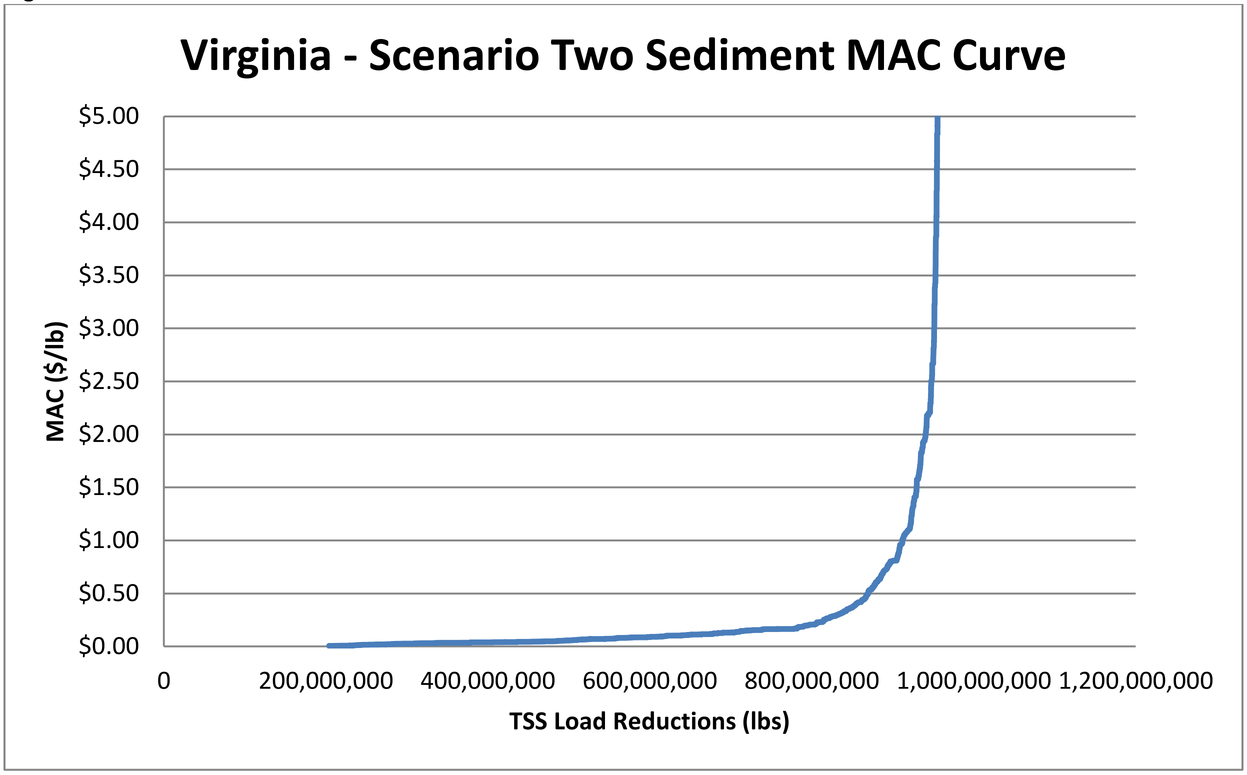

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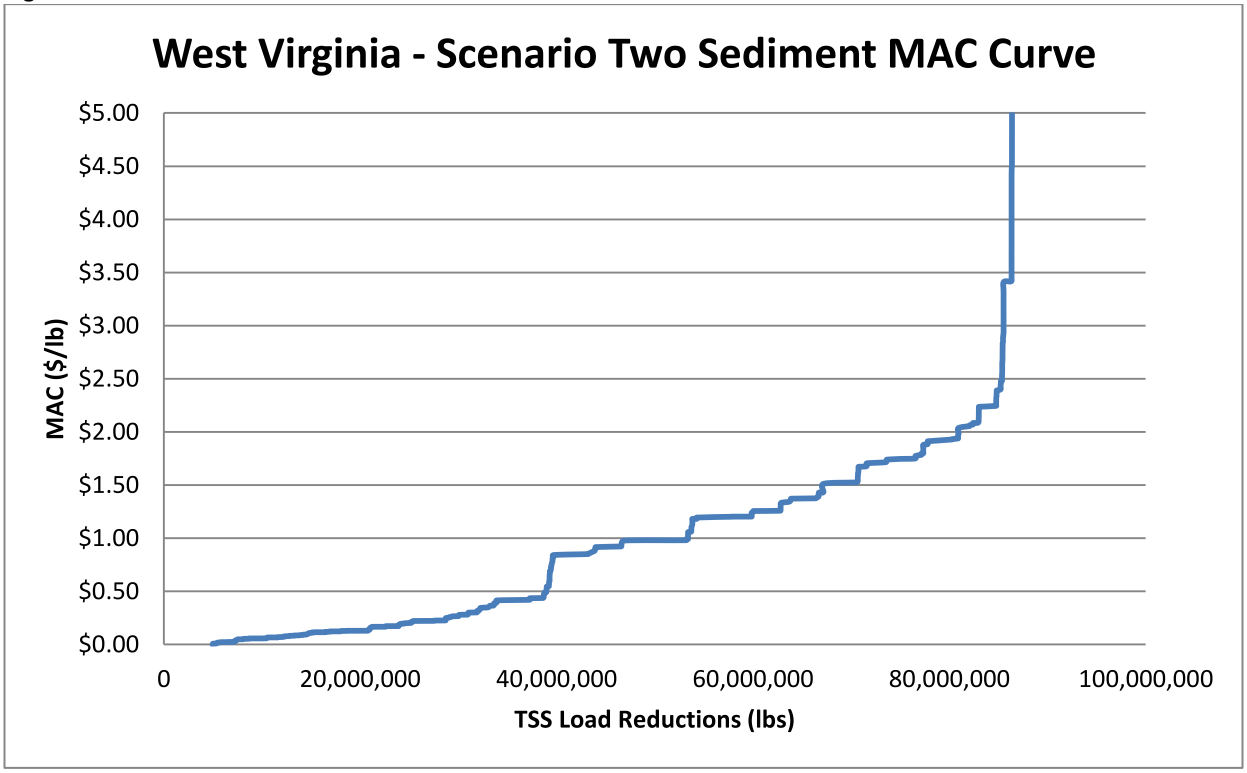

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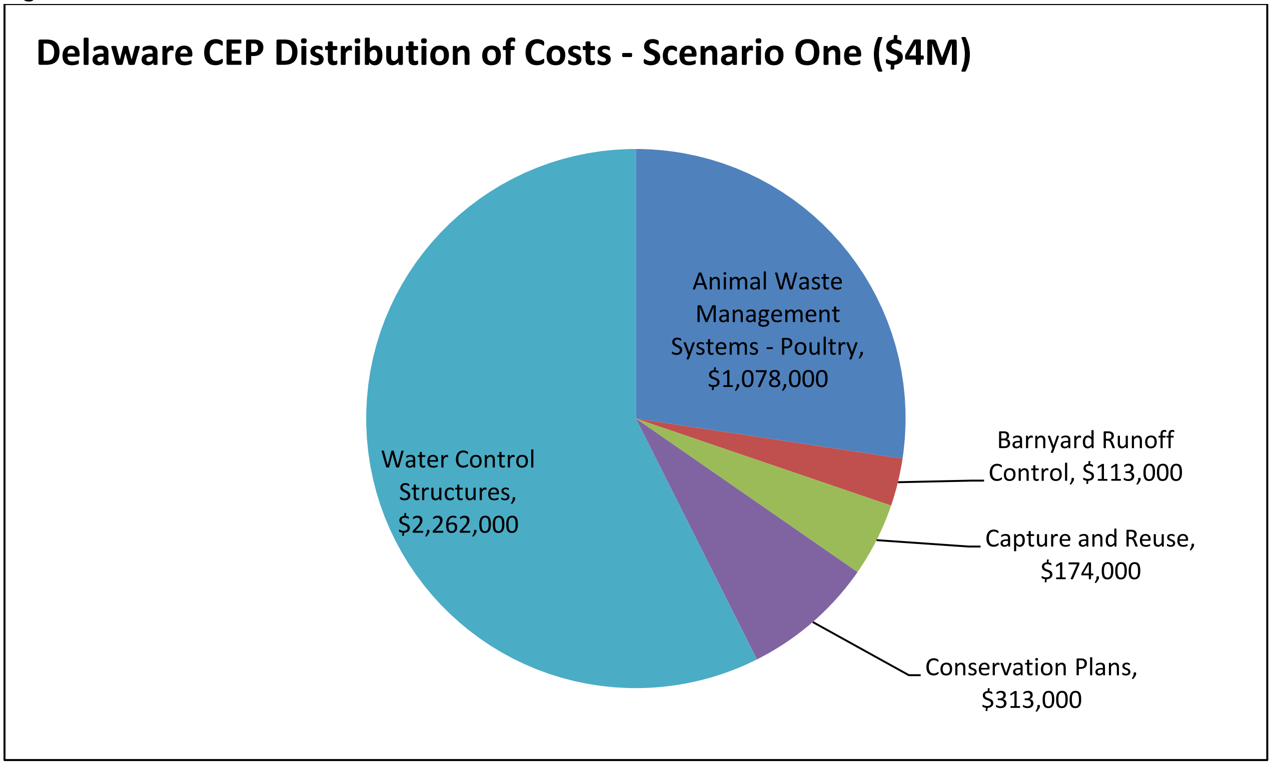

*Zero cost practices adopted but not listed: tillage practices, nutrient management (DE and PA according to USEPA/Abt Unit Costs), Cropland Irrigation (adopted in DE and MD only), phytase, dairy precision feeding

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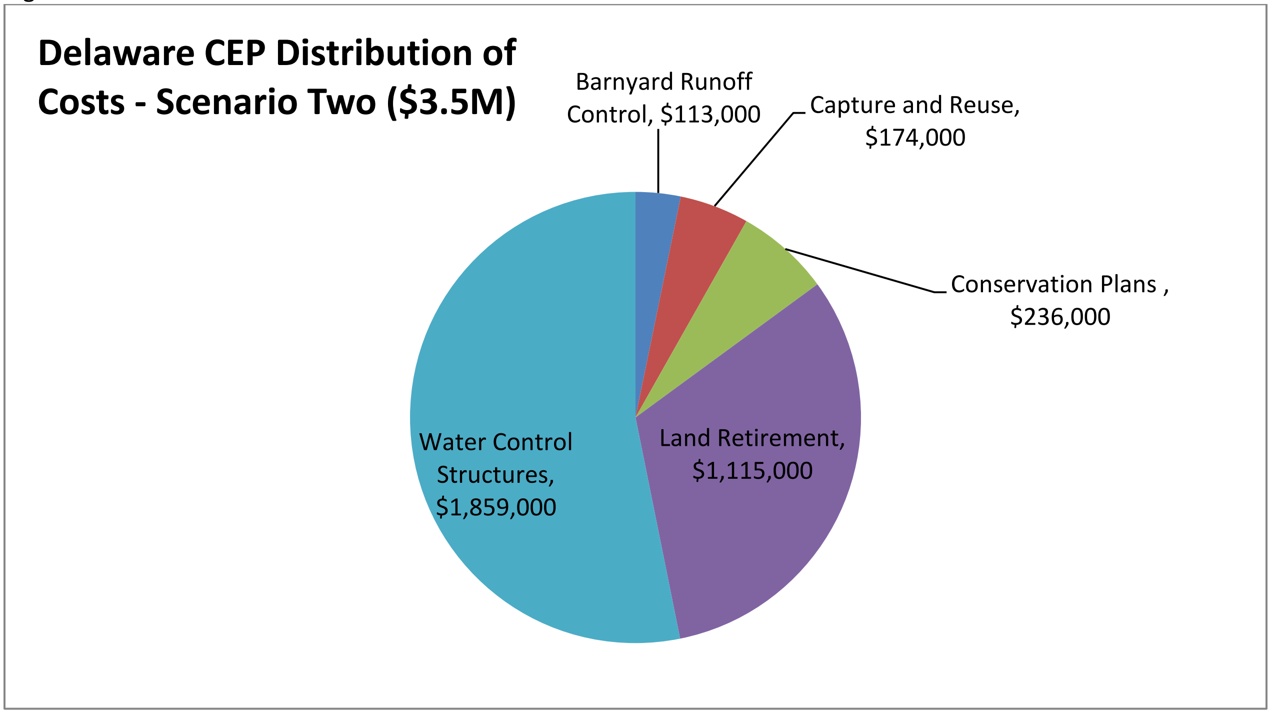

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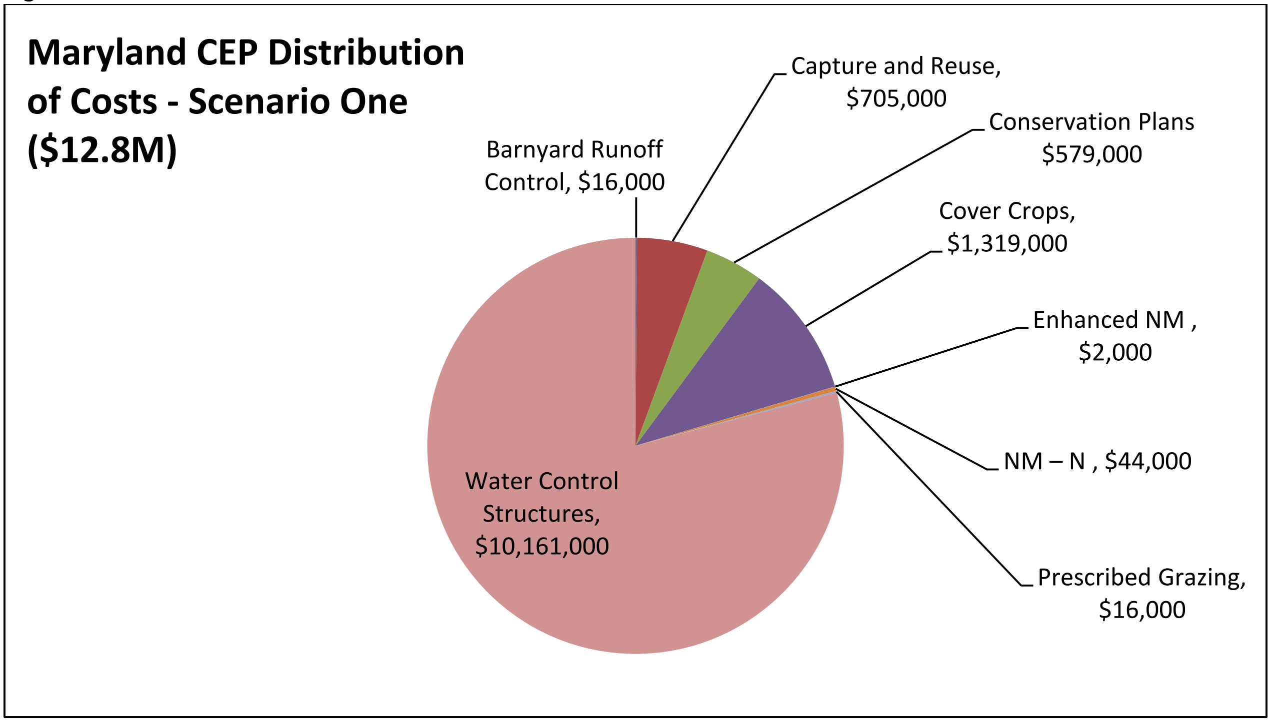

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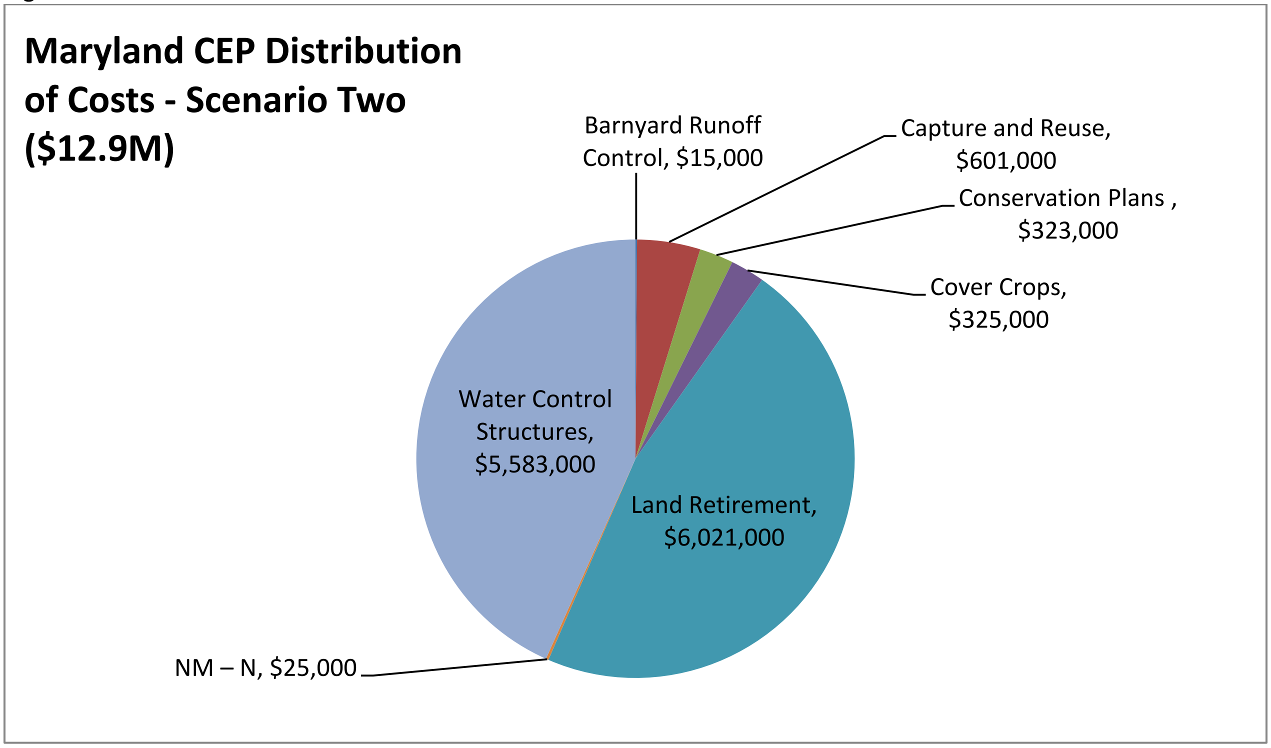

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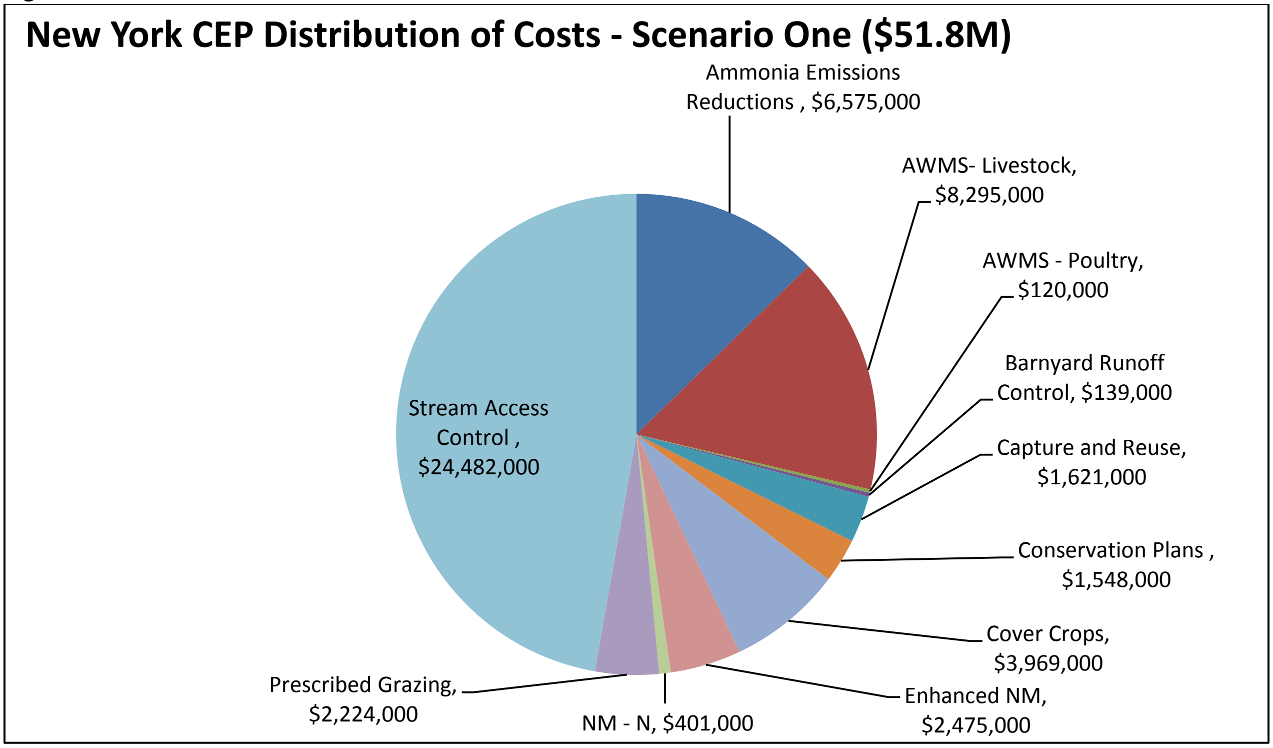

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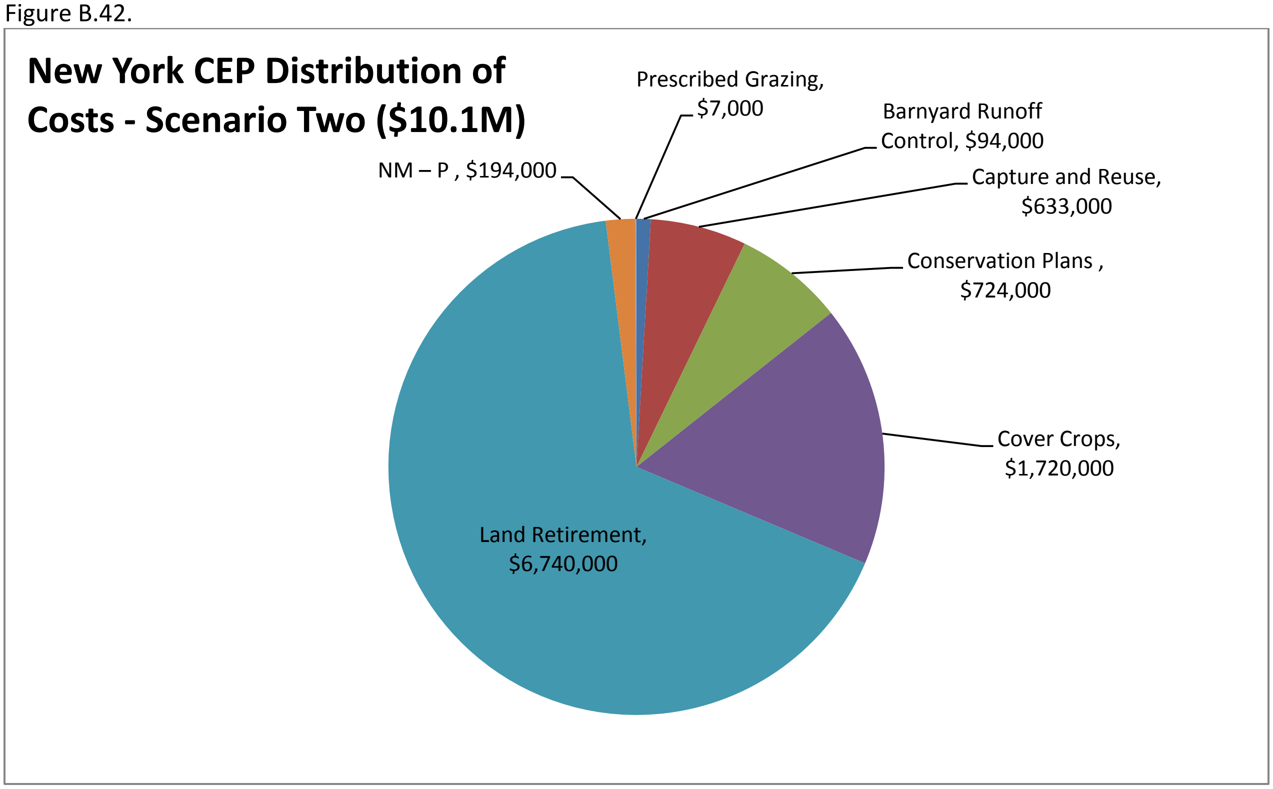

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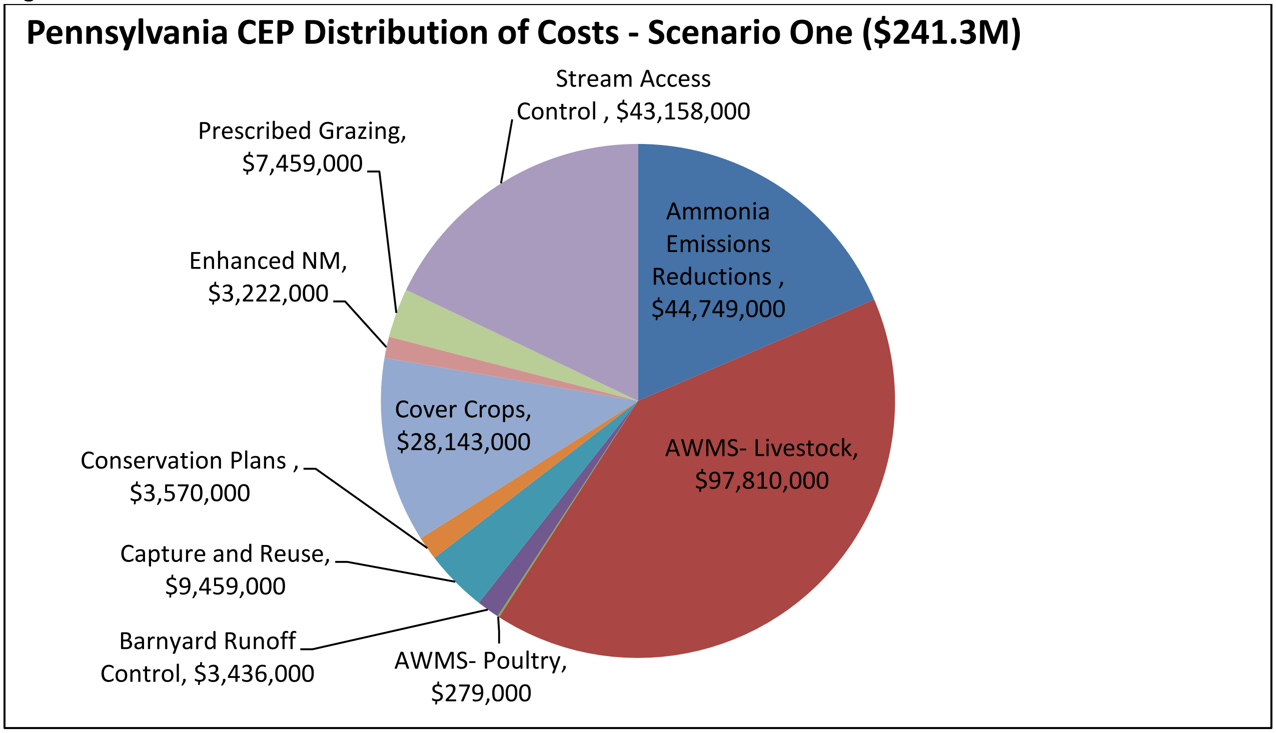

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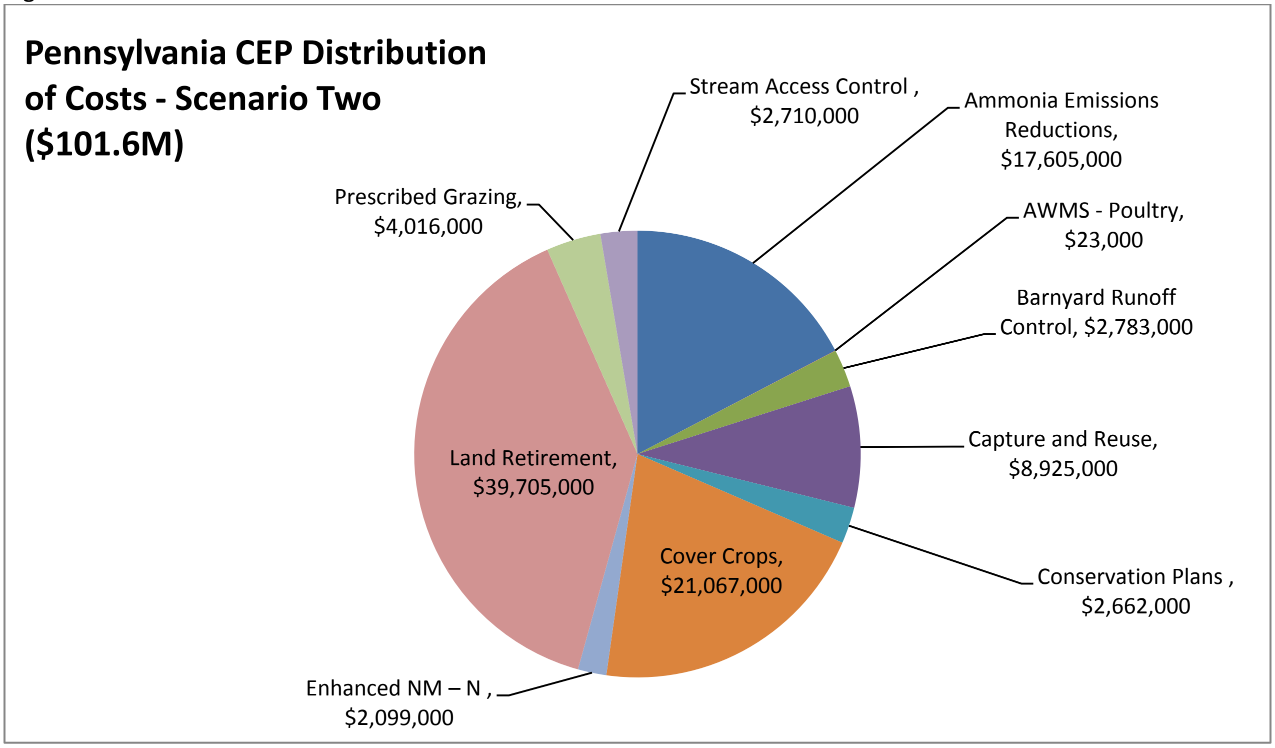

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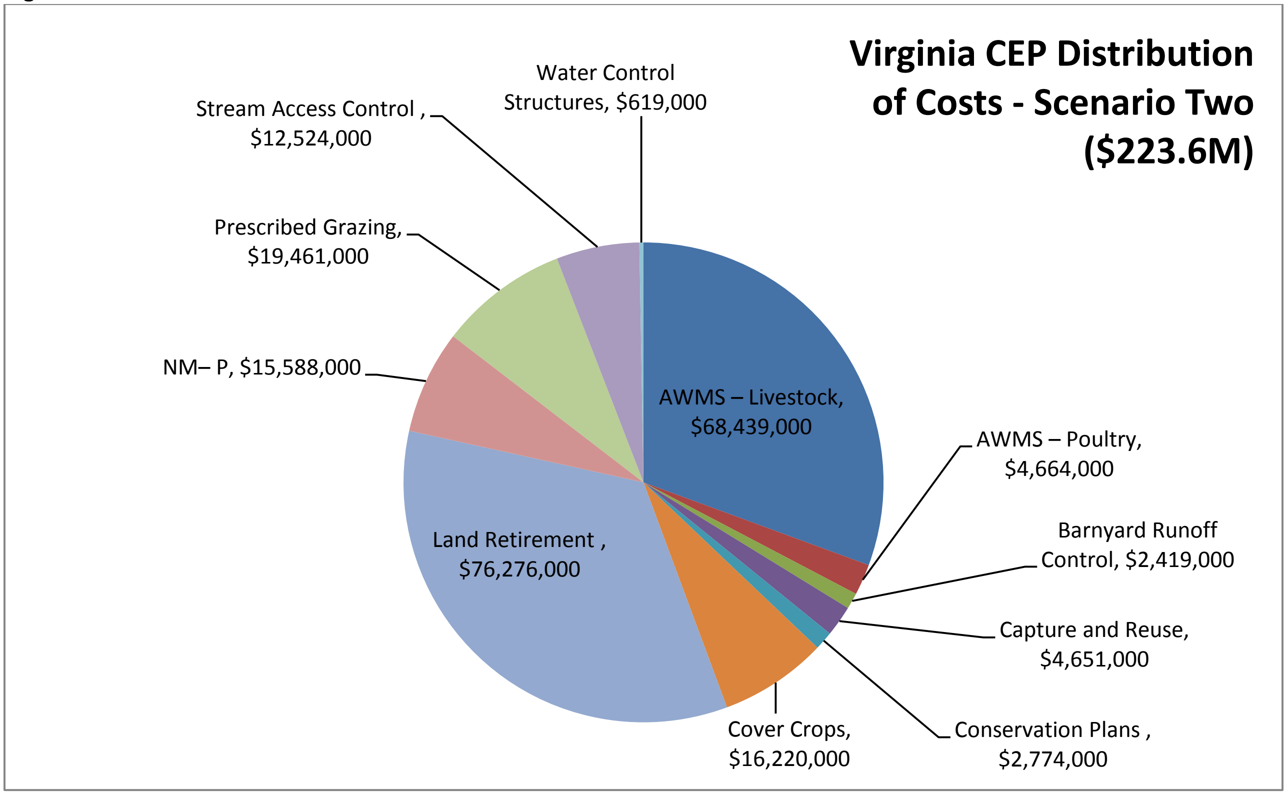

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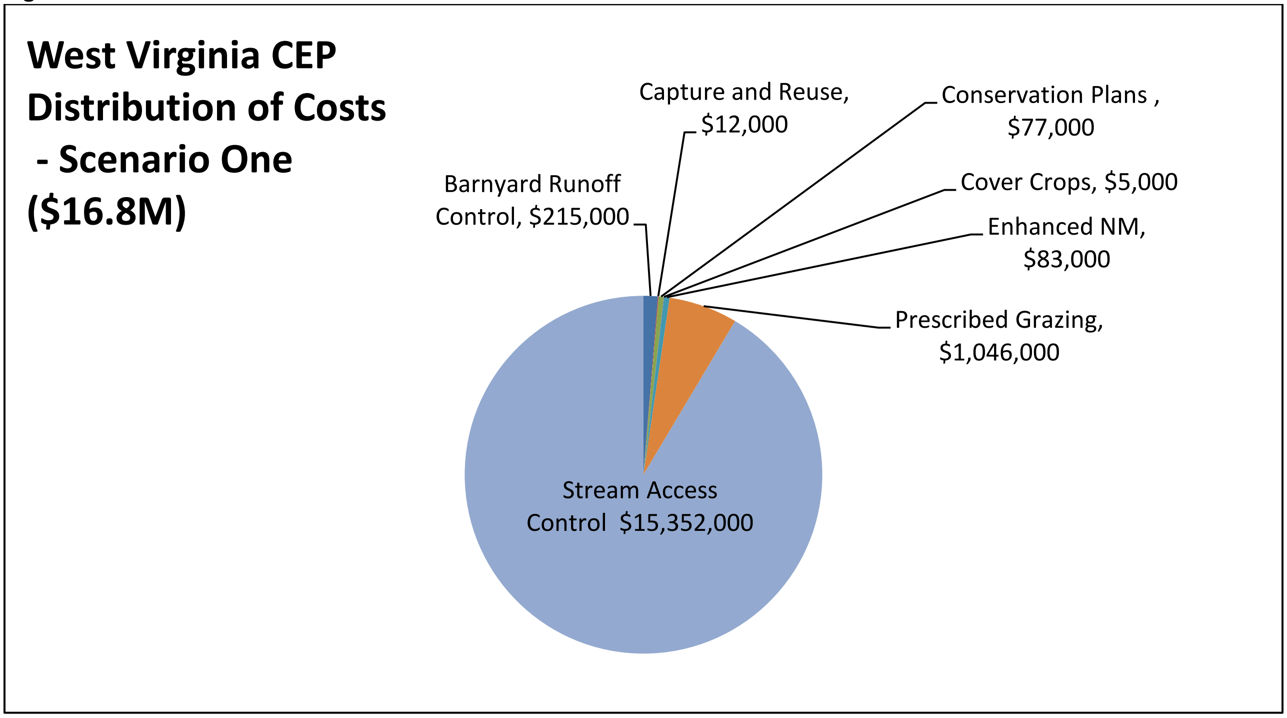

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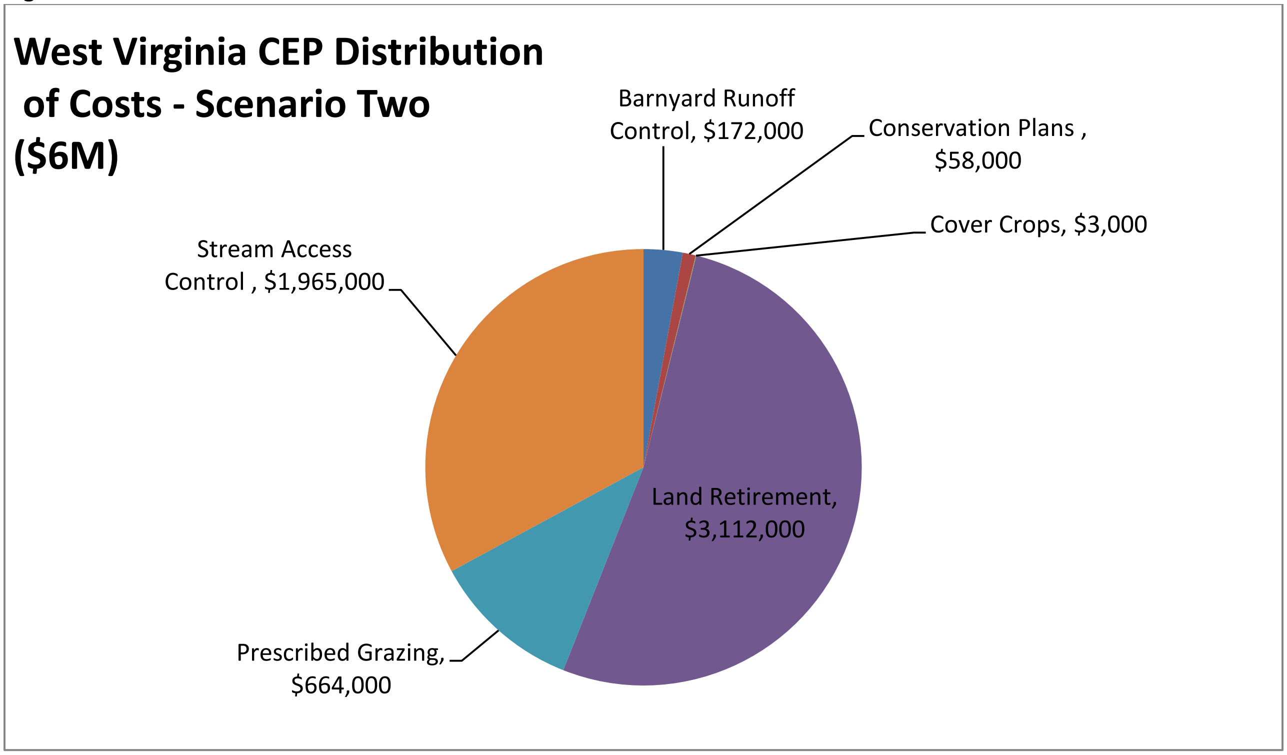

*Zero cost practices adopted but not listed: tillage practices, nutrient management (DE and PA according to USEPA/Abt Unit Costs), Cropland Irrigation (adopted in DE and MD only), phytase, dairy precision feeding

Appendix C: BMP Unit Costs

As discussed, NRCS payment schedules serve as the primary data source for BMP unit costs. We discuss the major characteristics of the cost data below. Any adjustments that we made to the USEPA cost data for the purposes of our analysis are noted. Finally, point five below lists BMP-specific exceptions to the USEPA cost data. In general, the adjustments we made are minor and do not create large deviations between our cost estimates and USEPA CBP cost estimates.

1) Data Source Inconsistencies: Estimating BMP costs is a nontrivial task given that there are thousands of BMPs, that BMPs individually and in combination with others (BMPs are typically implemented in combinations) are technologically and economically complex when viewed from a whole-farm perspective, and that the costs of any individual BMP can be highly varied across space. The USEPA/Abt estimates rely on existing data sources, with unit costs estimated at the state level in some cases. Ideally, cost data would be drawn from consistent sources utilizing identical methodologies and would be spatially specific at a finer level of geographic detail than the state level. However, at present there is very limited data on BMP costs in general and at spatial scales below the state level. Further, there is variability in what some of the agricultural BMPs actually mean in practice. These issues raise validity and reliability concerns when using the available BMP cost estimates to cost out the WIPs. They also create significant limitations on the use of the data to assess the potential for water quality trading between point and nonpoint sources, or among nonpoint sources. Gains from trading hinge on cost heterogeneity among alternative pollution sources. The limited spatial specificity in the data is sure to understate real world cost heterogeneity and thus potential gains from trade.

Further, the spatial variability in the cost estimates appears in some cases to be due to regional differences in the methodology used to calculate costs rather than genuine regional differences in the costs of various practices.

Though NRCS payment schedules serve as the primary source for USEPA jurisdiction cost estimates, other estimates are drawn from a wide variety of sources. Cost estimates for each BMP include a unit cost for each Chesapeake Bay jurisdiction. In many cases cost estimates are either (a) available for only a subset of jurisdictions or (b) are estimates for the entire Chesapeake Bay or a general estimate that is not spatially targeted. In cases where there are estimates for only a subset of the jurisdictions, USEPA uses the average of existing jurisdiction cost estimates to fill in missing jurisdiction costs. Thus, if cost estimates for a BMP are only available for Delaware, Maryland, and Pennsylvania, estimates for the remaining jurisdictions would be the average of these cost estimates. In cases where estimates are drawn from a more general source, this unit cost is applied to each jurisdiction. Some sources are outdated and few are peer-reviewed. These data source differences make it difficult to discern the cause of variation in the data, though recent iterations of the USEPA cost estimates are more consistently sourced from payment schedules and individual state-level departments such as the Maryland Department of Agriculture (MDA) and Virginia Department of Conservation and Recreation (VA DCR).

We made adjustments when possible to produce estimates that reflect geographical similarities rather than a simple average of all jurisdiction estimates (adjacent and non-adjacent) used in the Abt/USEPA estimates. Specifically, for those BMPs that include estimates for a subset of the jurisdictions, a simple average of estimate(s) for adjacent state(s) within the

Chesapeake Bay Watershed was utilized for jurisdictions lacking a cost estimate. For example, assume a BMP includes unit cost estimates for New York, Maryland, and Virginia but not Pennsylvania. Using our methodology, the cost estimate for Pennsylvania would be the average of those for New York and Maryland since they are adjacent to Pennsylvania.

2) Within Source Variation: In several cases there are large geographical variations across jurisdictions in BMP costs derived from NRCS payment schedules. For example, the cost of mortality composters ranges from $28/AU in New York to $1,120 in Virginia in the USEPA cost estimates, with each estimate based on data from their respective NRCS payment schedules. The cost of tree planting varies from $79.30 in Delaware to $291.22 in Maryland. Once again, data are drawn from state-specific NRCS payment schedules. These estimates differ from the USEPA estimates in that we use the NASS state average soil rental rate for the opportunity cost of removing land from production while USEPA uses CREP payments. Regardless, the variation in costs persists in both sets of estimates. There is significant geographical variation in costs for many other BMPs as well. Some of this variation can likely be explained by differences in NRCS BMP definitions and the technologies used to calculate costs in the state-specific payment schedules. Ultimately, geographical variation in costs can be attributed to a variety of sources and these are difficult to determine. However, given the existing data and resource constraints discussed, we elected to use the USEPA cost estimates with some minor adjustments to help preserve consistency.

3) Opportunity Costs of Land: The Abt/USEPA cost estimates account for the opportunity cost of removing farmland from production for land conversion BMPs (forest and grass buffers, tree planting). They do so using the Conservation Reserve Enhancement Program (CREP) payments for these BMPs and an assumed $5 annual maintenance cost. CREP targets the conservation of highly sensitive lands by paying landowners attractive rental rates to retire that land for a period of 10 to 15 years. CREP payments vary by jurisdiction and are based on Farm Service Agency (FSA) state average soil rental rates plus an additional percentage of the rental rate that varies by practice and jurisdiction. For example, the average rental rate for Delaware is $89/acre with riparian buffers and wetland restoration paying 195% of this amount and filter strips paying 132% of this amount. Some states, like Delaware, cap the rental payment at certain dollar levels per acre per year (i.e. $150) (USDA FSA 2011). As a result, opportunity costs can vary widely. While CREP rental payments do accurately reflect government costs for land conversion BMPs placed on highly sensitive land, they do not necessarily reflect the opportunity cost incurred by a farmer for removing farmland from production. Furthermore, CREP is a relatively small subcomponent of the Conservation Reserve Program (CRP). The rate for lands retired under CRP is generally the National Agricultural Statistics Service (NASS) county soil rental rate. NASS rental rates are based on observed rental market transactions.

To obtain a better estimate of the opportunity costs of land, we utilize the NASS state average rental rates for dry cropland to account for opportunity costs instead of CREP payments. This reduces the variation in opportunity costs across the watershed jurisdictions and more accurately mirrors observed rental market transactions.

4) Annualization: BMP costs are expressed in an annualized form that spreads the total costs over the anticipated lifespan of the BMP. Annualized costs are appropriate because they reflect the annual cost of installing and maintaining a BMP over its lifespan and allow the comparison of unit costs for BMPs with different lifespans. Applicable BMPs are annualized using a real discount rate of 7%. This rate is the “base case” discount rate for regulatory and benefit-cost analysis required by the Office of Management and Budget (OMB Circular No. A-94).

5) Exceptions for Specific BMP Costs: The following BMP-specific cost adjustments were deemed appropriate for our analysis. They represent differences between our cost estimates and those used by USEPA, but the resulting deviation in estimated costs is small.

- Crop Irrigation Management: Farmers likely benefit from this practice, so we have assigned it a cost of $0.
- Manure Transport: USEPA cost estimates assign different costs to manure transported within and out of the CBW due to different hauling distances. Unless there is an incentive payment, farmers will seek an alternative to manure transport rather than voluntarily paying more to transport manure longer distances. Therefore, we assign the average haul cost of $27.53/ton to manure transported both within and out of the watershed.