APPENDIX B
METHODS FOR ESTIMATING COSTS AND LOAD REDUCTIONS FOR AGRICULTURAL BMPS

B.1 Introduction

To estimate nutrient credits from agricultural sources, we estimated the cost and nutrient reductions associated with 13 agricultural BMPs in the Chesapeake Bay:

- **Cover crop early drilled rye**—The use of cover crops involves planting a secondary crop that is not intended for harvest but rather for soil enhancement and erosion prevention.
- **Continuous no-till agriculture**—This method for growing crops excludes the practice of tilling the soil, with the objective of increasing water retention and reducing soil erosion.
- **Enhanced nutrient management**—This practice involves reducing nitrogen applied to cropland as chemical and natural fertilizer, such that plant uptake is matched with nutrient availability.
- **Decision Agriculture**—This BMP includes several practices, such as crop and soil testing, to allow more efficient fertilizer application, resulting in less nitrogen runoff.
- **Riparian grass buffers**—These buffers are strips of land covered in grasses that are located between a potential pollutant source (e.g., an agricultural field) and a body of surface water.
- **Riparian forest buffers**—These buffers are strips of land covered in trees that are located between a potential pollutant source (e.g., an agricultural field) and a body of surface water.
- **Tree planting**—This practice involves planting and nurturing trees to convert existing agricultural land to forest.
- **Wetland restoration**—This practice involves returning agricultural land that was drained to allow crop and livestock production to their natural/historic function as wetlands.
- **Land retirement**—This practice involves allowing land to return to a more natural vegetative cover and suspending all agricultural activities but possibly allowing other low-impact activities (such as hunting) and conversion to forest.
- **Livestock stream exclusion**—This practice involves establishing fences and other structures to exclude livestock from streams and other waterways (only applied to degraded riparian pasture).

- **Off-stream watering**—This practice involves providing a source of clean water for livestock as an alternative to streams. Livestock will spend less time watering in streams, which will reduce the corresponding direct nutrient contributions.
- **Upland prescribed grazing**—This practice reduces the impact of livestock on pastureland by managing grazing patterns to improve the forages grown and avoid degraded areas of upland pastures.
- **Upland precision intensive rotational grazing**—Similar to upland prescribed grazing, this practice reduces the impact of livestock on pastureland by managing grazing patterns to improve the forages grown and avoid degraded areas of upland pastures but requires more intensive management for very short livestock rotation schedules.

B.2 Spatial Assumptions and Mapping Areas Available and Suitable for Agricultural BMPs

To appropriately estimate BMP implementation costs and associated nutrient load reductions, we relied on several publicly available spatial data sources, including the following:

- **The Chesapeake Bay Watershed Model 5.3.2 (CBWM) (USPEA, 2010)**—The CBWM provides the spatial unit of analysis for our model. It subdivides the Chesapeake Bay watershed into a linked network of 2,448 land–river segments. This segmentation combines county-level boundaries with subwatershed boundaries for the watershed's river reach network. In addition, data from the CBWM are used to specify the number of agricultural acres, assumed BMP implementation, and delivered nutrient loads by land-river segment upon achievement of the TMDL. In addition to segmentation, we relied on CBWM land use data (adapted from the 2006 NLCD). This dataset provides 30 m x 30 m pixels of land use within the watershed. We used this dataset to estimate the percentage of pasture and cropland in each land-river segment that is a) within the riparian area for forest and buffers, b) on hydric soils, and c) on highly erodible soils.
- **The National Hydrography Dataset (NHD)**—The NHD provides digital spatial data representing the surface water network in the Chesapeake Bay watershed. For this analysis, we used the "high resolution" NHD, which is based on 1:24,000-scale topographic mapping. This dataset provides a more detailed (i.e., higher resolution) representation of the reach network than the CBWM. This additional detail was used to identify the land area within each land-river segment that is potentially available for installing grass or forest buffer BMPs.
- **The Soil Survey Geographic (SSURGO)**—This database was used to identify land areas in each land–river segment with soils that are classified as hydric or highly erodible. This designation was used to identify lands that were potentially suitable for installing wetland or land retirement BMPs in each land–river segment.

We placed a series of restrictions on agricultural BMP implementation (**Table B-1**). For example, certain BMPs, such as continuous no-till agriculture, do not apply to pastureland, while upland prescribed grazing does not apply to cropland.

Using the CBWM to define BMP implementation under the TMDL, we excluded new BMPs from being applied in areas where they are assumed to be implemented. In particular:

- Areas being treated by an existing forest or grass buffer are not available for a new forest or grass buffer.
- Areas currently being treated by enhanced nutrient management are not available for enhanced nutrient management.
- Areas currently being treated by any cover crops are not available for another early drilled rye.
- Areas currently being treated by continuous no-till are not available for continuous no-till, enhanced nutrient management, or cover crop early drilled rye.[1]
- Areas currently being treated by off-stream watering, upland prescribed grazing, or upland precision intensive rotational grazing are not available for off-stream watering, upland prescribed grazing, or upland precision intensive rotational grazing.

The only area available for livestock exclusion is land classified as "degraded riparian pasture" within the CBWM. In order to estimate the potential benefits of adding a forest or grass buffer, we multiplied the riparian area by 5 to estimate the area potentially affected buffers on a degraded riparian pasture and adjusted nutrient loads to reflect the weighted average of one-fifth degraded riparian pasture and four-fifths pasture land. We subtracted the additional pasture area potentially affected by buffers on degraded riparian pasture from overall pasture acres within that land–river segment to prevent double-counting.

To estimate the percentage of crop and pastureland available for wetland restoration, we overlaid SSURGO hydric soils data with the CBWM land use data. Since the wetland restoration BMP is assumed to treat 4 times its area, we multiply the hydric soils by 5 to estimate the total area converted and treated by wetland restoration (limited to the total area within the land-river segment and land use). To estimate the percentage of crop and pastureland available for land retirement, we overlaid SSURGO highly erodible soils data with the CBWM land use data. For land–river segments with missing data on highly erodible soils, we applied the watershed average for each land use.

[1] In the CBWM, acres using continuous no-till agriculture are assumed to also be using enhanced nutrient management and cover crops.

Table B-1. Assumed Relationship between Land Characteristics and Suitability for Selected Agricultural BMPs

Land Characteristics	BMP Type									
	Grass Buffer	Forest Buffer	Conversion to Forest	Land Retirement	Livestock Exclusion	Restored Wetlands	Cover Crop	No-Till	Enhanced Nutrient Mgmt	Upland Grazing
Cropland	●	●	●	●		●	●	●	●	
Pastureland	●	●	●	●		●				●
Degraded riparian pasture	●	●	●	●	●					
Hydric soil	●	●	●	●	●	●	●	●	●	●
Nonhydric soil	●	●	●	●	●		●	●	●	●
Within riparian area	●	●	●	●	●	●	●	●	●	●
Outside riparian buffer			●	●		●	●	●	●	●
Highly erodible soil	●	●	●	●	●	●	●	●	●	●
Nonhighly erodible soil	●	●	●		●	●	●	●	●	●

We estimated the percentage crop and pastureland available for forest and grass buffers using both the CBWM land use dataset and the high resolution NHD. Land use adjacent to land classified as “open water” within the CBWM land use dataset is defined as riparian area and available for buffers. Land use not classified as open water that intersected streams within the NHD and the adjacent land use is also defined as riparian area. The NHD riparian area is adjusted to account for the stream area. We assumed an average stream width of 20 ft.[1] We subtraced from this riparian area the area converted to buffers under the TMDL and the area of degraded riparian pasture remaining in the CBWM model. Similar to wetland restoration, we multiplied the riparian area available for buffer by 5 to estimate the total area converted and treated by buffers. In addition to these restrictions, we required that no more than 25% of agricultural land can be converted to alternative land uses for each unique combination of land–river segment, land use, existing BMPs, and whether the area is within the riparian area, on hydric soil, and on highly erodible soils.

B.3 Methods for Estimating BMP Cost and Nutrient Load Reductions

Several key nutrient loading and cost variables are required to estimate BMP cost and nutrient load reductions:

- estimates of cost per acre for each BMP,
- delivered per-acre nutrient loads (TMDL Scenario of the Chesapeake Bay Watershed Model), and
- delivered per-acre nutrient load reductions accomplished by each BMP.

Each of these data sources and the methods of estimation are discussed below.

B.3.1 BMP Costs per Acre

For this study, we relied primarily on data for EPA’s BMP cost estimates generated to estimate the cost of the Chesapeake Bay TDML.[2] The annualized total cost of each BMP into three primary components: land, installation, and maintenance costs. Each of these components is defined as follows:

- **Annual Land Rental Costs**—These costs are included to reflect the opportunity costs of removing land from cultivated crops or pasture use, in locations where the BMP will result in a change of land use.

[1] Methodology developed under advisement of Peter Claggett, USGS.
[2] We relied on EPA’s draft cost estimates available December 2011 (CBPO, 2012, in progress).

- **Installation Costs**—These costs relate to the actual time, labor, capital, and materials used in designing and constructing the BMP.
- **Annual Maintenance Costs**—These costs are incurred in repairing, maintaining, and monitoring the BMP each year after it is constructed.

An important distinction between these costs is that installation costs are only incurred once in the life of the BMP, whereas land rental and BMP maintenance costs are incurred continually. Therefore, installation costs must be annualized in order to be compared with annual land rental and BMP maintenance costs.

Estimates of the per-acre costs for each BMP used in our analysis are reported in Table B-2. Cropland annual land rental rates were based on county-level estimates of 2011 soil rental rates for the Conservation Reserve Program (CRP). To estimate pasture rental rates, we multiplied the CRP soil rental rates by the county-level ratio of pastureland to cropland rental rates from the 2010 USDA Cash Rents Survey (NASS, 2010). In addition, all land rental rates are adjusted to reflect different rental payments made to different BMPs by states.

Table B-2. BMP Costs per Acre Installed or Implemented ($2010)

Best Management Practice	Annualized Total Costs ($/acre/year)	BMP Time Horizon
Riparian Forest Buffer	$98–$903	15
Riparian Grass Buffers	$44–$632	15
Wetland Restoration	$318–$887	15
Tree Planting	$56–$840	15
Land Retirement	$19–$624	10
Livestock Exclusion	$88–$693	10
Cover Crop Early Drilled Rye	$35	1
Continuous No-Till Agriculture	$20–$40	1
Enhanced Nutrient Management	$19	1
Decision Agriculture	$13–$30	1
Off Stream Watering	$32	10
Upland Prescribed Grazing	$9–$33	1
Upland Precision Intensive Rotational Grazing	$53–$93	1

BMP-specific installation and maintenance cost estimates are primarily based on costs from various sources collected by EPA. For two BMPs—land retirement and livestock exclusion—we applied estimates from Wainger and King (2007) to make use of county-level rental rates. However, several modifications were made to achieve consistency across cost estimates. First, these costs were adjusted for inflation and are represented in 2010 dollars. Second, installation costs were annualized using a 7% discount rate over the time periods reported in Table B-2.

To allow the model to choose among mutually exclusive options, we adjusted costs and loading reductions to reflect the area converted and treated. For instance, cover crops treat the entire area where applied, whereas a forest buffer involves land conversion within the riparian area and treatment of nutrients from four times the converted area. Equation B.1 captures how costs are estimated.

$$CostBMP = PercConvBMP \times CostInstall + PercConvBMP \times CostLand \qquad (B.1)$$

where

$Cost_{BMP}$	The annual cost per acre of available land for the BMP ($/acre/yr).
$PercConv_{BMP}$	Percentage of land assumed to be converted relative to the total area converted and treated.
$Cost_{Install}$	Annualized per-acre BMP installation and maintenance costs ($/installed acre/yr).
$Cost_{Land}$	Per-acre land rental by land type (crop or pasture) ($/converted acre/yr).

B.3.2 Baseline Delivered Nutrient Loads per Acre

To estimate nonpoint-source nutrient loadings delivered to the Bay for each of the various land uses in the Chesapeake Bay on a per-acre basis, we used and adapted the land classification and loadings data from the CBWM Phase 5.3. The land-use types that were most relevant for evaluating the nutrient removal associated with agricultural BMPs include the following:

- alfalfa (hay)
- alfalfa nutrient management (hay)
- unharvested forest (forest)
- hay with nutrients (hay)
- hay with nutrients nutrient management (hay)
- hay without nutrients (hay)

- high-till with manure (high-till)
- high-till with manure nutrient management (high-till)
- high-till without manure (high-till)
- high-till without manure nutrient management (high-till)
- low-till with manure (low-till)
- low-till with manure nutrient management (low-till)
- pasture (pasture)
- pasture nutrient management (pasture)
- degraded riparian pasture

To make the analysis tractable, we combined these various agricultural land-use types (excluding forest) into five agricultural categories—high-till, low-till, hay, pasture, and degraded riparian pasture. Using the CBWM data, we first calculated the *baseline total* nutrient loads for each land use category for each land–river segment. We then estimated *baseline per-acre* nutrient loads (by land-river segment) for the acres with different combinations of existing BMPs.

To estimate nutrient loading on areas with *no* current BMPs, we used the following equation:

$$\text{Loading}_{\text{NoBMP}}/\text{Acre} = \text{Loading}_{\text{LRSeg}}/[\text{Acres}_{\text{NoBMP}} + \sum_{i=1}^{N}(\text{AcresBMP}_{\text{i}} \text{ x } (1\text{-Eff}_{\text{BMPa}}))] \quad \text{(B.2)}$$

where

$\text{Loading}_{\text{NoBMP}}/\text{Acre}$	Per-acre loading (lbs. per year) of nitrogen or phosphorus (by land-river segment) on acres where no BMPs are current being applied
$\text{Loading}_{\text{LRSeg}}$	Total loading (lbs per year) of nitrogen or phosphorus within a land–river segment.
$\text{Acres}_{\text{NoBMP}}$	Acres not treated by a BMP within a land–river segment.
$\text{Acres}_{\text{BMPi}}$	Acres treated by BMP type (i) within the land–river segment.
Eff_{BMPa}	Effectiveness of BMP type (i) within the land–river segment.(i.e., fraction of pollutant load removed on acres where the BMP is applied)

For acres currently applying BMP type a, we estimated per-acre loads as:

$$Loading_{BMPa}/Acre = (Loading_{NoBMP}/Acre) \times (1-Eff_{BMPa}) \tag{B.3}$$

where

$Loading_{BMPa}/Acre$ Per-acre loading of nitrogen or phosphorus within a land-river segment when BMP type (a) is applied.

This equation was repeated for all BMPs available in our study (forest and grass buffers, cover crops, enhanced nutrient management, decision agriculture, continuous no-till, off stream watering, upland prescribed grazing, and upland precision intensive rotational grazing) and possible combinations of these BMPs within the land–river segment. Because a variety of different cover crops with different removal efficiencies may be implemented in a land–river segment, we took the weighted average of the removal efficiencies for all varieties as the cover crop removal efficiency in that land–river segment for the equations above.

B.3.3 Delivered Nutrient Load Reductions per Acre for Each BMP

This section discusses the methods used for estimating nutrient removal across each of the 13 BMPs included in this analysis. The effectiveness of different BMPs depends in part on where they are implemented. There are 14 unique hydrogeomorphic regions specified in the CBWM—areas of unique physiography and rock type that may have characteristic water-quality and biological response to natural variability and changes in nutrient inputs—across which BMP effectiveness may vary. The hydrogeomorphic regions include the following:

- Appalachian Plateau Carbonate
- Appalachian Plateau Siliciclastic
- Blue Ridge
- Coastal Plain Dissected Uplands—Nontidal
- Coastal Plain Dissected Uplands—Tidal
- Coastal Plain Lowlands—Nontidal
- Coastal Plain Lowlands—Tidal
- Coastal Plain Uplands—Nontidal
- Coastal Plain Uplands—Tidal
- Mesozoic Lowlands

- Piedmont Carbonate
- Piedmont Crystalline
- Valley and Ridge Carbonate
- Valley and Ridge Siliciclastic

Because nutrient mitigation differs across BMP and location, descriptions of how delivered nutrient removal per-acre was estimated are provided separately below for each individual BMP.

B.3.3.1 Riparian Forest Buffers

Riparian forest buffers mitigate nutrients in two ways. First, they reduce nutrients by changing the use of land along a waterway from cropland or pastureland to forest, which has a lower nutrient loading rate. Second, they treat effluent from cropland and pastureland draining through the buffer.

Calculating the reduction in delivered nutrient loading resulting from the change in the land use along a waterway is simply the difference in delivered nutrient loading rates between the existing land use and forest. Using the CBWM data, a per-acre loading rate for forest land in each land-river segment was estimated by dividing the total annual delivered loads from the forest land category by the total acres of forest in the land–river segment.

We assumed that buffers are placed only within the riparian area and treat effluent from four times the area converted for nitrogen and two times the area for phosphorus (Equation B.4). The percentage of the nutrients removed from the effluent being treated depends on the hydrographic location of the buffer, classified within the CBWM for each land–river segment. The removal efficiency rates used are reported in Table B-3.

$$\begin{aligned}\text{LoadRed/Acre} = {} & \text{PercConv}_{BMP} \text{ x } (\text{Loading}_{LRSeg} - \text{Loading}_{BMP}) + \\ & \text{PercConv}_{BMP} \text{ x TreatRatio x } (\text{Loading}_{LRSeg} \text{ x } \text{Eff}_{BMP})\end{aligned} \quad \text{(B.4)}$$

where

LoadRed/Acre	Per-acre delivered nitrogen or phosphorus load reduction associated with the BMP (lbs/acre/yr).
Loading_{LRSeg}	Per-acre estimated TMDL delivered nitrogen or phosphorus load for the baseline land use type (lbs/acre/yr)

$Loading_{BMP}$	Per-acre estimated TMDL delivered nitrogen or phosphorus loads for the BMP land use type (lbs/acre/yr) (e.g., forest)
TreatRatio	Treatment ratio for the BMP.; this parameter equals 4 for nitrogen and 2 for phosphorus
Eff_{BMP}	Removal efficiency of the BMP (%)

Table B-3. Removal Efficiency Rates for Riparian Forests by Hydrogeomorphic Region

Hydrogeomorphic Region	Nitrogen	Phosphorus
Appalachian Plateau Carbonate	0.54	0.42
Appalachian Plateau Siliciclastic	0.54	0.42
Blue Ridge	0.34	0.3
Coastal Plan Dissected Uplands—Nontidal	0.65	0.42
Coastal Plan Dissected Uplands—Tidal	0.19	0.45
Coastal Plan Lowlands—Nontidal	0.56	0.39
Coastal Plan Lowlands—Tidal	0.19	0.45
Coastal Plan Uplands—Nontidal	0.31	0.45
Coastal Plan Uplands—Tidal	0.19	0.45
Mesozoic Lowlands	0.34	0.3
Piedmont Carbonate	0.46	0.36
Piedmont Crystalline	0.56	0.42
Valley and Ridge Carbonate	0.34	0.3
Valley and Ridge Siliciclastic	0.46	0.39

Source: CBWM

B.3.3.2 Riparian Grass Buffers

The procedure for estimating nutrient removal from riparian grass buffers is essentially identical to that used for riparian forest buffers previously discussed (Equation B.4). The primary differences are that grass buffers (1) are represented as a change in land use from crop or pasture to the “hay without nutrients” land category and (2) typically remove less effluent from up-gradient acres (i.e., they typically have lower removal efficiencies than forest buffers). For each land–river segment, a per-acre loading rate for hay-without-nutrient lands was estimated by dividing (1) the total annual delivered loads from the hay-without-nutrient land category by (2) the total acres of hay-without-nutrient land in the land-river segment.

The grass buffer removal efficiency rates used for this analysis are reported in Table B-4.

B.3.3.3 Wetland Restoration

The nutrient removal associated with wetland restoration was estimated similar to riparian buffers. It was assumed that restored wetlands reduce nutrients in two ways. First, they reduce nutrients by changing the use of land where they are placed to forest (consistent with CBWM), which has a lower nutrient-loading rate. Second, they treat effluent from four times the area converted for nitrogen and two times the area for phosphorus (Equation B.4). The percentage of nutrients removed from effluent depends on the hydrogeomorphic region of the wetland. The removal efficiency rates used are reported in Table B-5.

Table B-4. Removal Efficiency Rates for Grass Buffer by Hydrogeomorphic Region

Hydrogeomorphic Region	Nitrogen	Phosphorus
Appalachian Plateau Carbonate	0.38	0.42
Appalachian Plateau Siliciclastic	0.38	0.42
Blue Ridge	0.24	0.3
Coastal Plan Dissected Uplands—Nontidal	0.46	0.42
Coastal Plan Dissected Uplands—Tidal	0.13	0.45
Coastal Plan Lowlands—Nontidal	0.39	0.39
Coastal Plan Lowlands—Tidal	0.13	0.45
Coastal Plan Uplands—Nontidal	0.21	0.45
Coastal Plan Uplands—Tidal	0.13	0.45
Mesozoic Lowlands	0.24	0.3
Piedmont Carbonate	0.32	0.36
Piedmont Crystalline	0.39	0.42
Valley and Ridge Carbonate	0.24	0.3
Valley and Ridge Siliciclastic	0.32	0.39

Source: CBWM

Table B-5. Removal Efficiency Rates for Wetlands by Geomorphic Region

Geomorphic Province	Nitrogen	Phosphorus
Appalachian	0.07	0.12

Geomorphic Province	Nitrogen	Phosphorus
Piedmont, Valley and Ridge, Blue Ridge, Mesozoic Lowlands	0.14	0.26
Coastal Plain	0.25	0.50

Source: CBWM

B.3.3.4 Land Retirement

Estimating the nutrient removal from land retirement is a relatively straightforward process because this BMP only reduces delivered nutrients to the Bay by changing land use to hay without nutrients. Thus, the removal efficiency is simply the change in loading between the two land uses (Equation B.5). Because nutrient loading differs by land–river segment, the loading reduction will also naturally differ by land–river segment.

$$\text{LoadRed/Acre} = \text{Loading}_{\text{LRSeg}} - \text{Loading}_{\text{BMP}} \quad \text{(B.5)}$$

B.3.3.5 Tree Planting

Similar to land retirement, nutrient removal is only achieved from changing land use to forest (Equation B.5).

B.3.3.6 Livestock Exclusion

Within the CBWM, livestock exclusion is assumed to be only applicable to land classified as degraded riparian pasture. Nutrient reductions are estimated as a change in land use from degraded riparian pasture to hay without nutrients, similar to land retirement.

B.3.3.7 Cover Crop Early Drilled Rye

Cover crops are grown during or between primary cropping seasons in order to reduce nutrient runoff from cropland. For example, if an acre of cropland generated five pounds of nitrogen per year in the absence of a cover crop, then applying a cover crop to that acre would reduce nutrient loading by some fraction. If the cover crop in question had a nitrogen removal efficiency of 20%, then nitrogen loading from that acre of cropland would be reduced by one pound (Equation B.6).

$$\text{LoadRed/Acre} = \text{Loading}_{\text{LRSeg}} \times \text{Eff}_{\text{BMP}} \quad \text{(B.6)}$$

Based on these cost and nutrient efficiency estimates for the various cover crops, early drilled rye is both the most effective and least costly to apply. Because the model would always choose this option over the other possible cover crops, we only included early drilled rye as a cover crop option in our model, which has an efficiency of 15% for phosphorus (0% phosphorus efficiency on low-till cropland). The efficiency for nitrogen varies by hydrogeomorphic region, with 45% efficiency in the Coastal Plain and 34% in the Non-Coastal Plain. Other cover crop efficiencies were used to estimate the baseline loadings as described in Section B.3.2 (Table B-6).

Table B-6. Removal Efficiency Rates for Early Drilled Rye Cover Crops by Hydrogeomorphic Region

Hydrogeomorphic Region	Nitrogen	Phosphorus
Appalachian Plateau Carbonate	0.45	0.15
Appalachian Plateau Siliciclastic	0.34	0.15
Blue Ridge	0.34	0.15
Coastal Plan Dissected Uplands—Nontidal	0.45	0.15
Coastal Plan Dissected Uplands—Tidal	0.45	0.15
Coastal Plan Lowlands—Nontidal	0.45	0.15
Coastal Plan Lowlands—Tidal	0.45	0.15
Coastal Plan Uplands—Nontidal	0.45	0.15
Coastal Plan Uplands—Tidal	0.45	0.15
Mesozoic Lowlands	0.34	0.15
Piedmont Carbonate	0.45	0.15
Piedmont Crystalline	0.45	0.15
Valley and Ridge Carbonate	0.45	0.15
Valley and Ridge Siliciclastic	0.34	0.15

Source: CBWM

B.3.3.8 Continuous No-Till Agriculture

Continuous no-till agriculture is a method for growing crops that excludes the practice of tilling the soil with the objective of increasing water retention and reducing soil erosion. As a result, pursuing continuous no-till agriculture directly reduces nutrient loads from the land on which it is applied. The specific removal efficiencies used in this analysis were obtained from the CBWM (Phase 5.3) and vary across the three pollutants and three geomorphic regions (Table B-7).

Table B-7. Removal Efficiency Rates for Continuous No-Till by Hydrogeomorphic Region

Hydrogeomorphic Region	Nitrogen	Phosphorus
Non-Coastal Plain	0.15	0.40
Coastal Plain	0.10	0.20

Source: CBWM

B.3.3.9 Enhanced Nutrient Management

This practice involves decreasing the nitrogen applied to cropland as inorganic or organic fertilizer by 15% (such that plant uptake is better matched with nutrient availability). Like cover crops, enhanced nutrient management directly reduces the nitrogen loads from the land on which it is applied (Equation B.6). Removal efficiency for this BMP within the CBWM is 7% for nitrogen and 0% for phosphorus.

B.3.3.10 Decision Agriculture

This includes several practices, such as crop and soil testing, to allow more efficient fertilizer application, resulting in less nitrogen runoff. Like cover crops, decision agriculture directly reduces the nitrogen loads from the land on which it is applied (Equation B.6). Removal efficiency for this BMP within the CBWM is 3.5% for nitrogen and 0% for phosphorus.

B.3.3.11 Off Stream Watering

This practice involves providing a source of clean water for livestock as an alternative to streams. Livestock will spend less time watering in streams, which will reduce the corresponding direct nutrient contributions. This BMP results in a direct reduction in nutrient loads from the land on which it is applied (Equation B.6). Removal efficiency for this BMP within the CBWM is 5% for nitrogen and 8% for phosphorus.

B.3.3.12 Upland Prescribed Grazing

This practice reduces the impact of livestock on pastureland by managing grazing patterns to improve the forages grown and avoid degraded areas of upland pastures. This BMP results in a direct reduction in nutrient loads from the land on which it is applied (Equation B.6). Removal efficiency for this BMP within the CBWM is 10% for nitrogen and 20% for phosphorus.

B.3.3.13 Upland Precision Intensive Rotational Grazing

Similar to upland prescribed grazing, this practice reduces the impact of livestock on pastureland by managing grazing patterns to improve the forages grown and avoid degraded areas of upland pastures, but requires more intensive management for very short livestock rotation schedules. This BMP results in a directly reduction in nutrient loads from the land on which it is applied (Equation B.6). Removal efficiency for this BMP within the CBWM is 9% or 11% for nitrogen in different hydrogeomorphic regions and 24% for phosphorus (Table B-8).

B.3.4 Overlapping BMP Application

We assume that certain combinations of BMPs are also applicable on agricultural land. For instance a forest buffer can be installed in the riparian area, and cropland behind the forest buffer can be treated with a cover crop. The 13 BMPs included have an additional 40 possible combinations of BMPs. To estimate the load reductions associated with overlapping BMPs, we combined the load reduction relationships described in Equations B.4 to B.6. For

Table B-8. Removal Efficiency Rates for Upland Precision Intensive Rotational Grazing by Hydrogeomorphic Region

Hydrogeomorphic Region	Nitrogen	Phosphorus
Appalachian Plateau Carbonate	0.09	0.24
Appalachian Plateau Siliciclastic	0.11	0.24
Blue Ridge	0.11	0.24
Coastal Plan Dissected Uplands—Nontidal	0.09	0.24
Coastal Plan Dissected Uplands—Tidal	0.09	0.24
Coastal Plan Lowlands—Nontidal	0.09	0.24
Coastal Plan Lowlands—Tidal	0.09	0.24
Coastal Plan Uplands—Nontidal	0.09	0.24
Coastal Plan Uplands—Tidal	0.09	0.24
Mesozoic Lowlands	0.11	0.24
Piedmont Carbonate	0.09	0.24
Piedmont Crystalline	0.11	0.24
Valley and Ridge Carbonate	0.09	0.24
Valley and Ridge Siliciclastic	0.11	0.24

example, for the combined forest buffer and cover crop early drilled rye BMP, we combined Equations B.4 and B.6 into Equation B.7, where BMP type (a) is a forest buffer and BMP type (b) is cover crop early drilled rye.

$$\text{LoadRed/Acre} = \text{PercConv}_{BMPa} \times (\text{Loading}_{LRSeg} - \text{Loading}_{BMPa}) +$$

$$\text{PercConv}_{BMPa} \times \text{TreatRatio} \times (\text{Loading}_{LRSeg} \times (1\text{-Eff}_{BMPb}) \times \text{Eff}_{BMPa}) +$$

$$(1 - \text{PercConv}_{BMPa}) \times (\text{Loading}_{LRSeg} \times \text{Eff}_{BMPb}) \qquad \text{(B.7)}$$

where

PercConv_{BMPa}	Percentage of land assumed to be converted relative to the total area converted and treated for BMP type (a).
Loading_{BMPa}	Per acre estimated delivered nitrogen or phosphorus for the BMP type (a) land use.
Eff_{BMPa}	Removal efficiency of the BMP type (a)
Eff_{BMPb}	Removal efficiency of the BMP type (b)

To estimate the costs of overlapping BMPs, we adjust the per-acre costs of land-applied BMPs to reflect whether the other BMPs involve land conversion (Equation B.8).

$$\text{Cost}_{BMPa,b} = \text{Cost}_{BMPa} + \text{PercConv}_{BMPa} \times \text{Cost}_{BMPb} \qquad \text{(B.8)}$$

where

$\text{Cost}_{BMPa,b}$	The annual cost per acre of available land for the overlapping BMP types (a) and (b) ($/acre/yr).
Cost_{BMPa}	The annual cost per acre of available land for BMP type (a) ($/acre/yr).
Cost_{BMPb}	The annual cost per acre of available land for BMP type (b) ($/acre/yr).

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