Attachment J-1:

Sediment Management Options for the Conowingo Dam Restricting Sediment in the Watershed by Implementing Best Management Practices

Sediment Management Options for the Conowingo Dam
Restricting Sediment in the Watershed
by
Implementing Best Management Practices

Introduction

The purpose of this report is to examine how implementation of best management practices related to the E3 scenario (Everything, Everywhere, by Everyone) for the Chesapeake Bay can potentially reduce sediment loads to the Susquehanna River and to develop a range of costs to implement those practices.

The Susquehanna River extends 444 miles from its source at Otsego Lake near Cooperstown, NY to the head of the Chesapeake Bay at Havre de Grace, MD and drains 27,510 square miles from tributaries in New York, Pennsylvania, and Maryland (Susquehanna River Basin Commission) (Figure 1).

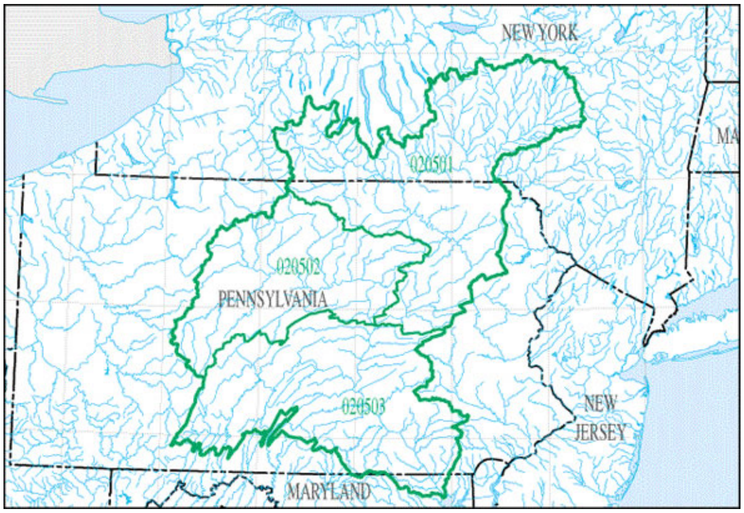

Figure 1. Susquehanna River watershed (Mansfield University).

The Susquehanna River is the nation's 16th largest river and of all the tributaries, it contributes the largest amount of freshwater flow, nutrients, and sediment to the Chesapeake Bay. The 1990-2012 average monitored sediment load to the Chesapeake Bay measured from the non-tidal areas of the Bay's nine largest rivers was 5.4 million tons per year, which does not include the sediment loads generated in the Coastal Plain (Chesapeake Bay Program). The 1990-2012 average monitored sediment load from the Susquehanna River was 2.15 million tons per year, or approximately 40 percent of the total load from non-tidal areas (Figure 2) (Joel Blomquist, personal communication).

Sediment transport by streams and rivers is a natural process; however, the delivery of excess sediment can have many deleterious effects, which include increased loads of nutrients, increased dredging of navigation channels, and adverse impacts to submerged aquatic vegetation and bottom-dwelling (benthic) organisms (Scientific and Technical Advisory Committee, 2000).

Sediment deposition to Chesapeake Bay from the Susquehanna River is mitigated by the presence of three consecutive hydroelectric dams (Safe Harbor Dam, Holtwood Dam, and Conowingo Dam). These three dams form a reservoir system in the lower part of the River that has been trapping sediment behind the dams since they were constructed in 1910 (Holtwood Dam), 1928 (Conowingo Dam) and 1931 (Safe Harbor Dam). The uppermost two dams, Safe Harbor Dam and Holtwood Dam, have already reached their capacity to store sediment and sediment-related nutrients. Conowingo Reservoir, which is formed by Conowingo Dam, the lowermost and largest dam, has reached approximately 92 percent of its sediment storage capacity and is therefore in a state of dynamic equilibrium (Langland, 2015).

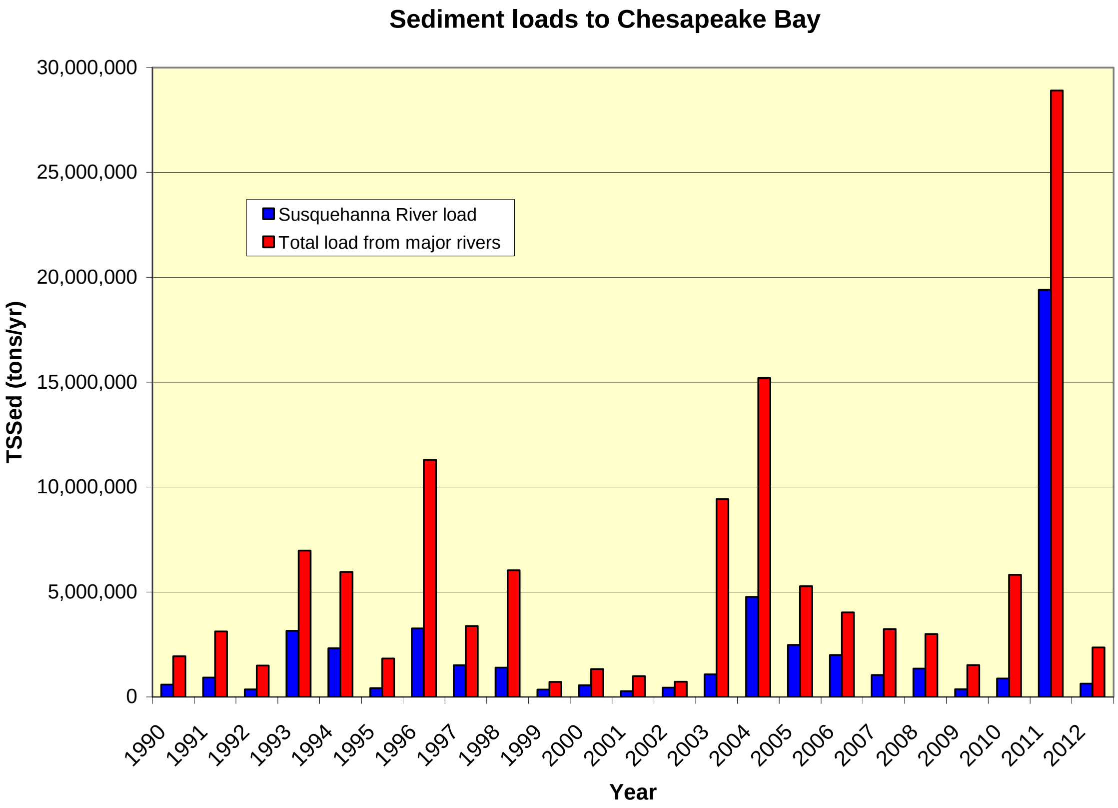

Figure 2. Total sediment loads and Susquehanna River sediment loads to Chesapeake Bay

Although the Conowingo Reservoir has not reached its full capacity, there is little room left. As a result, during periods of high flow trapped sediment may be re-suspended and deposited below Conowingo Dam in the upper Chesapeake Bay. These re-suspension or major scour events (flows greater than 400,000 cubic feet per second) occurred in June 1972 during Tropical Storm Agnes, the floods of September 1975 and January 1996, and more recently in September 2011 during Tropical Storm Lee. Recent studies suggest that scouring may be occurring more frequently and that sediment concentrations and loads at high flows have increased over the past ten years (2002-2011; Hirsch, 2012). These scour events result in massive plumes of sediment such as the one that occurred following Tropical Storm Lee, which extended past the mouth of the Patuxent River (Figure 3) and originated from both the watershed and from scour behind the dams, with the majority of sediment coming from the watershed. It is currently estimated that the percent of scour to total load ranges from 20 percent to 37 percent (average 30 percent) for flows of 400,000 to 800.000 cubic feet per second (Langland, 2015).

Excess sediment and nutrient loads from all sources have resulted in the Bay not meeting its water quality standards for dissolved oxygen, water clarity, and chlorophyll-a, an indicator of algal biomass, and led the U.S. Environmental Protection Agency (EPA) to list the Bay as an impaired water-body. In December 2010 the EPA and Chesapeake Bay Program watershed partners Maryland, Pennsylvania, New York, Virginia, West Virginia, Delaware, and the District of Columbia implemented a Chesapeake Bay-wide Total Maximum Daily Load (TMDL) or “pollution diet,” which set limits of 185.9 million pounds of nitrogen, 12.5 million pounds of phosphorus, and 6.45 billion pounds (3.2 million tons) of sediment per year. The sediment TMDL would represent a 20-percent reduction over current Bay-wide loads. The EPA computer model estimated sediment loads to the Susquehanna River from New York, Pennsylvania, and Maryland and their TMDL allocations appear in Table 1.

Figure 3. NOAA satellite image showing sediment plume following Tropical Storm Lee in September 2011.

Table 1. Modeled sediment loads and TMDL allocations for New York, Pennsylvania, and Maryland from the Chesapeake Bay Program Phase 5.3.2 Watershed Model run for 2012 (U.S. EPA, 2010).

State	Current load (million pounds/year)	Allocated load (million pounds/year)
New York	317	293
Pennsylvania	2,200	1,741
Maryland	68	63
Total	**2,585**	**2,097**

To achieve the reductions outlined in the TMDL each of the six states and the District of Columbia developed watershed implementation plans (WIPs) which outline the best management practices (BMPs) they will put in place to meet their nutrient load allocations. Although there are state allocations for sediment loads in the TMDL they are not defined in the WIPs, because it is anticipated that achieving the TMDL goals for nitrogen and phosphorus will result in a sediment load reduction that exceeds the sediment load allocation. According to the WIPs for New York, Pennsylvania, and Maryland BMP implementation levels outlined in the plans to meet nutrient allocations are estimated to surpass the sediment planning targets (i.e., lower the loads) by approximately 62 million pounds per year.

Beyond the WIPs

Additional load reductions can theoretically be achieved by implementing the "E3" scenario, which calls for jurisdictions to implement every feasible practice everywhere (Everything, Everywhere, by Everyone). If the E3 scenario were implemented it is estimated that a total of 190 million pounds of sediment per year would be reduced Bay-wide (this includes the 62 million pounds per year that would be reduced by implementing the WIPs to meet the TMDL goals). It is important to note that the E3 scenario is a "what-if" scenario of watershed conditions with theoretical maximum levels of managed controls on load sources. There are no cost and few physical limitations to implementing the BMPs in the E3 scenario. Generally, E3 implementation levels and their associated reductions in nutrients and sediment could not be achieved for many practices, programs, and control technologies when considering physical limitations and levels of participation by the jurisdictions, therefore the estimated sediment load reductions and BMP implementation levels beyond the WIPs should be considered theoretical boundaries of maximum implementation and load reductions.

Methods and Assumptions

The Chesapeake Bay Program developed the E3 scenario from a list of approved agriculture and urban/suburban BMPs using output from the Phase 5.3.2 Watershed Model, which is also used for tracking towards the TMDL. Currently, there are 34 agriculture and 20 urban/suburban U.S. EPA Chesapeake Program-approved BMPs that are used to assess progress toward the Bay-wide TMDL (Attachment 1) and this list is constantly expanding to add new BMPs, and including revised BMPs to update existing practices (Kevin DeBell, Ph.D., personal communication). The list of approved BMPs used in the E3 scenario was developed by consensus among the seven jurisdictions in the Chesapeake Bay partnership at a series of expert panels, with workgroup and subcommittee approval. The technologies, practices, and programs selected by the partnership have been previously reported by the jurisdictions as part of annual model assessments, milestones, tributary strategies, and WIPs. The E3 scenario does not include the full suite of practices due to the goal of achieving maximum load reductions. The BMPs that are fully implemented in the E3 scenario were estimated to produce greater reductions than alternative practices that could be applied to the same land base (Jeff Sweeney, personal communication).

When implemented across the Susquehanna River watershed, these practices would in theory achieve significant reductions of sediment delivered to the reservoir behind Conowingo Dam. The model run outlined practices for New York, Pennsylvania, and Maryland and the units, in either acres or feet, required to achieve the reductions. There were 12 agriculture practices needed in New York, 13 in Pennsylvania, and 11 in Maryland. Examples include planting cover crops on over 1 million acres of farm land across the three states, improving pasture management on 591,000 acres, and developing conservation plans for approximately 3 million acres. There were nine urban/suburban practices needed for New York, 15 for Pennsylvania, and 18 for Maryland. Examples include installing a variety of storm water management practices on 1.1 million acres of land, controlling sediment on 171,000 acres, and restoring 77,000 feet of urban streams. Resource practices (forest harvesting and improving dirt and gravel roads) were also needed; however, these could be considered a subset of agriculture practices.

The Chesapeake Bay Program also developed watershed-wide unit costs for the approved BMPs, which are draft, subject to change, and part of a larger report that is still under review. Most, though not all, of the BMPs used in the E3 scenario have associated unit costs in dollars per acre per year or dollars per foot per year based on 2010 dollars. The primary source of the unit costs was the Bay Program approved list; however, in order to have as complete a cost estimate as possible, in the absence of unit costs from the Bay Program, costs from the Maryland Department of the Environment (MDE) (Greg Busch, personal communication), and costs from the Maryland Department of Agriculture (MDA) (John Rhoderick, personal communication) were used. In cases where costs for a jurisdiction were not available, a cost that was available for one jurisdiction was used for all three. Low and high costs were available for urban/suburban BMPs, though not for agriculture.

Agriculture unit costs were available for all three states. For New York, nine costs were obtained from the Bay Program-approved list, two were from MDE, and one from MDA. Costs for ten of the 13 agriculture BMPs for Pennsylvania were obtained from the Bay Program, two were from MDE, and one was from MDA. For Maryland, nine unit costs came from the Bay Program, two were obtained from MDE and one from MDA. Agriculture unit costs ranged from $2 per acre per year to develop conservation management plans to $482 per acre per year for wetland restoration.

Eight of the nine unit costs for New York urban/suburban BMPs were obtained from the Bay Program-approved list and one was obtained from MDE. Twelve unit costs were available from the Bay Program list for Pennsylvania, one from MDE, and no unit costs were available for the remaining two practices. Sixteen unit costs for Maryland were from the Bay Program list and two were obtained from MDE. There were two resource practices for New York and Pennsylvania, and one for Maryland. In the absence of unit costs from the Bay Program, costs from MDE were used for all three states. No costs were available for urban growth reduction, abandoned mine reclamation, and erosion and sediment control on dirt and gravel roads in

Pennsylvania, and erosion and sediment control on dirt and gravel roads in New York. These missing data represent an area of uncertainty in this analysis.

Five of the unit costs for urban/suburban BMPs were divided by the Bay Program into new/re-development and retrofits. The annual cost estimates for this project assumed that 10 percent of the urban/suburban practices would be implemented as new construction or re-development and 90 percent would be retrofits (retrofits are more costly than new construction or re-development). Some examples of urban/suburban unit costs are provided in Table 2.

Table 2. Examples of units costs for urban/suburban BMPs (Draft – subject to change).

Practice		New/re-development (dollars/acre/year)			Retrofits (dollars/acre/year)		
		NY	PA	MD	NY	PA	MD
Bio-swales	Low	$420	$395	$394	$612	$575	$574
	High	$1,549	$1,456	$1,453	$2,404	$2,258	$2,255
Impervious surface reduction	Low	$11,438	$11,438	$11,438	$11,438	$11,438	$11,438
	High	$17,222	$17,222	$17,222	$17,222	$17,222	$17,222
Urban forest buffers	Low	$121	$153	$92	$121	$153	$92
	High	$121	$153	$92	$121	$153	$92
Urban infiltration	Low	$663	$623	$622	$1,014	$953	$951
	High	$1,562	$1,468	$1,465	$2,545	$2,391	$2,387

Conclusions

The output from the Chesapeake Bay Program's Phase 5.3.2 Watershed Model, which was used to develop the practices in terms of the units acres or feet of BMP needed to implement the E3 scenario, was combined with the unit cost estimates from the Bay Program and other sources to develop a range in the annual cost of achieving the theoretical maximum amount of sediment reduction to the Conowingo Reservoir. One example of a BMP used in the Phase 5.3.2 Watershed Model run for the E3 scenario was wetland restoration. The number of acres in each state was multiplied by the respective unit cost in each state in dollars per acre per year to derive the cost for that BMP. The model used restoration of 133,140 acres of wetlands in Pennsylvania, 192 acres in Maryland, and 142,541 acres in New York at a combined annual cost of approximately $132,078,000. The cost of restoring wetlands for each state was combined with the cost of implementing the remaining agriculture and urban/suburban BMPs to derive the estimated annual costs by jurisdiction and the totals that appear in Table 3. The high cost estimates to implement the E3 scenario are provided in Attachment 2 and Attachment 3 for agriculture and urban/suburban BMPs, respectively. Unit costs and a description of the BMPs are provided in Attachment 4. The costs in Attachment 4 are draft, subject to change, and excerpted from a larger report that is in draft form and pending review. BMP cost efficiencies in terms of cost of BMP per pound of sediment reduced are provided in Attachment 5.

Table 3. Estimated costs by jurisdiction and annual costs to implement the E3 scenario

State	Low cost estimate	High cost estimate
Maryland	$8,429,749.50	$15,701,723.79
New York	$108,746,113.36	$139,680,705.69
Pennsylvania	$1,399,225,005.62	$3,356,594,812.19
Total	**$1,516,400,868.48**	**$3,511,977,241.67**

The low and high costs of implementing the E3 scenario in terms of dollars per cubic yard of sediment reduced per year are $12,929 and $29,944, respectively. These estimates are based on 95,000 tons of sediment reduced in the E3 scenario, and a conversion factor of 1 cubic yard of dredged material equaling 0.81 tons for a total of 117,284 cubic yards.

The cost of implementing the E3 scenario in Pennsylvania is considerably higher than New York and Maryland because most (76.2 percent) of the Susquehanna River watershed is in Pennsylvania. Maryland has the smallest part of the watershed (1 percent) and therefore the smallest cost. Twenty-two percent of the watershed is in New York.

The maximum available load of sediment that could be reduced by additional BMP implementation above and beyond the WIPs throughout the Susquehanna River watershed is approximately 95,000 tons per year. Based on the U.S. Geological Survey monitored loads for 1993 through 2012 this is about 4 percent of what is estimated to flow over Conowingo Dam into Chesapeake Bay on an average annual basis, which is approximately, 2.4million tons. Given the relatively small reduction in sediment reaching Conowingo Dam and the high cost, implementing the E3 scenario as a means to reduce scour events does not appear economically or practically feasible. Note that these numbers are subject to change and will be refined based on further analysis and review.

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Attachment 1:
List of U.S. EPA Chesapeake Bay Program Approved Best Management Practices

Chesapeake Bay Program Agriculture WIP BMPs
Alternative Watering Facilities
Ammonia Emissions Reduction
Animal Waste Management Systems - All
Animal Waste Management Systems – Livestock
Animal Waste Management Systems – Poultry
Barnyard Runoff Control
Capture and Reuse
Carbon Sequestration and Alternative Crops
Commodity and Small Grains Cover Crops
Conservation Plans
Conservation Tillage
Continuous No-Till
Cover Crops
Cropland Irrigation Management
Dairy Precision Feeding and Forage Management
Decision Agriculture
Enhanced Nutrient Management
Forest Buffers
Grass Buffers
Horse Pasture Management
Land Retirement
Liquid Manure Injection
Loafing Lot Management
Manure Transport - All
Manure Transport - Inside
Manure Transport - Outside
Mortality Composters
Non-Urban Stream Restoration
Nutrient Management
Phytase - Poultry
Phytase - Swine
Precision Intensive Rotational Grazing
Prescribed Grazing
Stream Access Control
Tree Planting
Water Control Structures
Wetland Restoration

Chesapeake Bay Program Urban/suburban WIP BMPs
Bioretention
Bioswale
CSO Separation
Dry Detention and Extended Detention Basins
Dry Detention Ponds/Hydrodynamic Structures
Erosion and Sediment Control
Forest Conservation
Impervious Surface Reduction
Retrofit Storm water Management
Street Sweeping
Urban Tree Planting
Urban Filtering Practices
Urban Forest Buffers
Urban Grass Buffers
Urban Infiltration Practices
Urban Nutrient Management
Urban Stream Restoration
Vegetated Open Channels
Wetlands and Wet Ponds
Storm Water Management by Era

Attachment 2:
Agriculture BMPs and Annual Costs to Implement the E3 Scenario
(Draft – subject to change)

Agriculture Practices	Units	2025 WIP + Sediment E3 Above Conowingo MD COST	2025 WIP + Sediment E3 Above Conowingo NY COST	2025 WIP + Sediment E3 Above Conowingo PA COST
Continuous NoTill	acres			
Other Conservation-Till	acres	$115,758.52	$2,392,456.27	$19,670,287.79
Conservation Tillage w/ Continuous NoTill	acres			
Cover Crop	acres	$288,474.70	$7,189,841.55	$29,678,349.48
Commodity Cover Crop	acres	$39,804.08	$899,469.56	$6,961,589.96
Commodity+Cover Crop	acres			
Pasture Alternative Watering	acres			
Prescribed Grazing	acres	$41,189.64	$2,206,643.78	$6,268,654.32
Horse Pasture Management	acres			
Stream Access Control with Fencing	acres	$882.49	$1,175,313.30	$1,351,218.12
Pasture Management Composite	acres			
Forest Buffers on Fenced Pasture Corridor	acres	$2,796.31	$2,916,190.89	$4,252,490.95
Grass Buffers on Fenced Pasture Corridor	acres			
Forest Buffers	acres	$503,236.96	$22,956,978.89	$117,758,978.66
Wetland Restoration	acres	$284,372.46	$22,018,893.26	$62,900,937.79
Land Retirement	acres	$80,944.75	$5,222,798.14	$7,324,194.16
Grass Buffers	acres			
Tree Planting	acres			
Carbon Sequestration	acres			$1,362,273.32
Conservation Plans	acres	$20,527.66	$1,336,017.45	$4,638,982.20
NonUrban Stream Restoration	feet	$2,537.57	$2,365,995.57	$2,433,605.80
Barnyard Runoff Control	acres	$11,799.38	$650,392.88	$3,407,132.71
Loafing Lot Management	acres			

Attachment 3:
Urban/suburban BMPs and Annual Costs to Implement the E3 Scenario
(Draft – subject to change)

		2025 WIP + Sediment E3	**2025 WIP + Sediment E3**	**2025 WIP + Sediment E3**
		Above Conowingo	**Above Conowingo**	**Above Conowingo**
		MD	**NY**	**PA**
		COST	**COST**	**COST**
Urban/Suburban Practices	**Units**			
Wet Ponds & Wetlands	acres	$176,953.31	$9,045,758.07	$122,795,122.53
Dry Ponds	acres	$262,894.83		$24,348,873.16
Extended Dry Ponds	acres	$116,172.73	$196,473.21	$26,540,271.74
Infiltration Practices	acres	$154,279.40	$27,679,287.11	$1,125,730,593.15
Filtering Practices	acres	$7,532,657.80	$7,774,856.42	$1,436,536,251.46
BioRetention	acres	$1,759.12		
BioSwale	acres	$24,053.29		
Vegetated Open Channel	acres	$50,061.60		
SWM by Era (1985-2002)	acres	$1,238,988.53		
SWM by Era (2002-2010)	acres	$645,246.86		
Retrofit Stormwater Management	acres	$165,852.02		
Stormwater Management Composite	acres			
Erosion and Sediment Control	acres	$40,084.45	$43,122.31	$4,039,577.85
Extractive Erosion and Sediment Control	acres		$13,273,106.72	$199,519,476.84
Forest Conservation	acres	$0.00		
Urban Growth Reduction	acres			
Impervious Surface Reduction	acres	$2,288,287.14	$2,381,785.38	$36,665,104.12
Forest Buffers	acres	$19,702.72		$2,182,307.54
Tree Planting	acres	$3,702.60		$141,150.28
CSO Connection	acres			$63,973,358.56
Urban Stream Restoration (feet)	feet	$39,221.40	$1,589,997.00	$2,978,751.42
Street Sweeping (lbs)	lbs	$1,538,662.24		
Street Sweeping	acres		$5,058,038.42	$39,165,795.80
Abandoned Mine Reclamation	acres			
Resource Practices				
Forest Harvesting BMPs	acres	$10,819.26	$1,307,289.51	$3,969,482.49
Dirt&Gravel Road E&S (feet)	feet			

Attachment 4:

U.S. Environmental Protection Agency Approved Best Management Practices

(Draft – subject to change, do not quote or cite)

This attachment describes the development of unit costs for each source category. Estimates of annualized costs reflect a 5% discount rate. Also included are the incremental costs for other actions.

Agricultural Sources

The Phase II WIPs identify a wide range of agricultural practices included in the accompanying spreadsheet of implementation levels [and thus included in the Chesapeake Bay Watershed Model (CBWM)]. This analysis includes only those practices in the spreadsheets and current watershed model.

EPA uses unit costs for agricultural sediment or nutrient controls identified in the WIPs from USDA's Environmental Quality Incentive Program (EQIP), where available, and WIPs and prior studies where EQIP estimates are not available. In selecting relevant studies, EPA excludes those prior to 2000, and relies on EQIP and WIP estimates where feasible because these costs likely represent the most recent and best estimates of actual implementation costs. For example, most states within the Bay watershed indicate that cost share payments represent average BMP costs estimated based on previously implemented contracts or unit costs (from sources such as RSMeans, vendor/local dealer quotes or estimates from technical assistance providers) and typical farm or operation size. In cases where documentation is insufficient to determine the basis for the estimates or conversion to the desired units of BMP implementation is not possible, EPA does not use the cost data.

When using EQIP costs, EPA estimates total implementation costs (or the sum of individual practice components), including funded amounts. For example, unit costs from the EQIP cost share program typically represent 75% of the total cost for a given unit of implementation in Maryland (Morgarte, 2011), West Virginia (Wolfe, 2011), Pennsylvania (Frantz, 2011), Delaware (Garrahan, 2011), New York (Swartz, 2011), and Virginia (Faulkner, 2011). As such, to estimate the total costs of BMPs based on EQIP costs, EPA multiplies the EQIP costs by 1.33 (1/0.75).

Exhibit 1 summarizes average unit costs for each agricultural practice, described in the following sections. Jurisdiction-specific estimates are available for only a subset of practices. When using unit costs, EPA uses overall average costs when jurisdiction-specific costs are not available.

Exhibit 1: Summary of Annual Unit Costs for Agriculture BMPs (2010$)

Chesapeake Bay WIP BMPs	Unit Costs							Units
	Average	DE	MD	NY	PA	VA	WV	
Alternative Watering Facilities	$30	NA	NA	NA	NA	NA	NA	$/acre/yr
Ammonia Emissions Reduction	$37	$46	$45	NA	$39	$46	NA	$/AU/yr
CAFO Animal Waste Management Systems - All	$170	NA	NA	NA	NA	$170	NA	$/AU/yr
AFO Animal Waste Management Systems - All	$170	NA	NA	NA	NA	$170	NA	$/AU/yr
CAFO Animal Waste Management Systems - Livestock	$194	NA	NA	NA	NA	$194	NA	$/AU/yr
AFO Animal Waste Management Systems - Livestock	$194	NA	NA	NA	NA	$194	NA	$/AU/yr
CAFO Animal Waste Management Systems - Poultry	$72	NA	NA	NA	NA	$72	NA	$/AU/yr
AFO Animal Waste Management Systems - Poultry	$72	NA	NA	NA	NA	$72	NA	$/AU/yr
Barnyard Runoff Control	$567	$822	$446	NA	NA	$434	NA	$/acre/yr
Capture and Reuse	$971	NA	$971	NA	NA	NA	NA	$/acre/yr
Carbon Sequestration and Alternative Crops	$18	NA	NA	NA	NA	NA	NA	$/acre/yr
Commodity and Small Grains Cover Crops	$67	$23	NA	NA	NA	$110	NA	$/acre/yr
Conservation Plans	$2	NA	$2	NA	NA	NA	NA	$/acre/yr
Conservation Tillage	$0	NA	NA	NA	NA	NA	NA	$/acre/yr
Continuous No-Till	$0	NA	NA	NA	NA	NA	NA	$/ac/yr
Cover Crops	NA	$52	$68	$75	$40	$109	$98	$/ac/yr
Cropland Irrigation Management	$42	$19	$92	NA	$25	$31	NA	$/acre/yr

Exhibit 1: Summary of Annual Unit Costs for Agriculture BMPs (2010$)

Chesapeake Bay WIP BMPs	Unit Costs							Units
	Average	DE	MD	NY	PA	VA	WV	
Dairy Precision Feeding and Forage Management	-$10	NA	NA	-$10	NA	NA	NA	$/AU/yr
Decision Agriculture	$25	$30	$32	NA	$13	NA	NA	$/acre/yr
Enhanced Nutrient Management	$8	NA	$9	NA	NA	NA	NA	$/acre/yr
Forest Buffers	$219	$177	$295	$231	$293	$94	NA	$/acre/yr
Grass Buffers	NA	$189	$204	$147	$191	$93	$123	$/acre/yr
Horse Pasture Management	$22	NA	NA	$20	NA	$23	NA	$/acre/yr
Land Retirement	$169	NA	$169	NA	NA	NA	NA	$/acre/yr
Liquid Manure Injection	$60	NA	$60	NA	NA	NA	NA	$/acre/yr
Loafing Lot Management	$1,541	NA	$1,943	NA	NA	$1,140	NA	$/acre/yr
Manure Transport - All	$28	NA	NA	NA	NA	NA	NA	$/ton/yr
Manure Transport - Inside	$16	NA	NA	NA	NA	NA	NA	$/ton/yr
Manure Transport - Outside	$39	NA	NA	NA	NA	NA	NA	$/ton/yr
CAFO Mortality Composters	$377	NA	NA	$28	$88	$1,120	$217	$/AU/yr
AFO Mortality Composters	$377	NA	NA	$28	$88	$1,120	$217	$/AU/yr
Non-Urban Stream Restoration	$7	NA	$7	NA	$5	NA	$8	$/feet/yr
Nutrient Management	NA	-$1	$6	$2	-$1	$12	$10	$/acre/yr
Phytase - Poultry	-$61	NA	NA	NA	NA	NA	NA	$/AU/yr
Phytase - Swine	-$41	NA	NA	NA	NA	NA	NA	$/AU/yr
Precision Intensive Rotational Grazing	$74	$53	$93	NA	NA	NA	$75	$/acre/yr
Prescribed Grazing	NA	$33	$15	$13	$16	$28	$9	$/acre/yr
Stream Access Control	$5,312	NA	NA	NA	NA	NA	NA	$/acre/y

Exhibit 1: Summary of Annual Unit Costs for Agriculture BMPs (2010$)

Chesapeake Bay WIP BMPs	Unit Costs							Units
	Average	DE	MD	NY	PA	VA	WV	
								r
Tree Planting	$171	$162	$212	NA	$255	$112	$155	$/acre/yr
Water Control Structures	$18	NA	NA	NA	NA	$18	NA	$/acre/yr
Wetland Restoration	NA	$475	$460	$543	$442	$384	$410	$/acre/yr

Alternative Watering Facilities and Stream Access Control

Alternative water facilities involve the use of permanent or portable livestock water troughs placed away from the stream corridor. The water supplied to the facilities can come from any source including pipelines, springs, wells, and ponds. In-stream watering facilities such as stream crossings or access points are not considered in this definition. As discussed in the model documentation, the CBWM also defines stream access control as 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 (e.g., through in-stream crossing or limiting watering facilities).

Weiland et al. (2009) developed unit costs for three off-stream watering alternatives: off-stream watering with no fencing (i.e., alternative watering facilities), and off-stream watering with fencing and with or without stream crossings (i.e., stream access control). For this analysis, EPA converts these costs into dollars per acre per year by dividing by the estimated costs by model farm size (50 acres) and annualizing over 20 years (based on the useful life of the practice).

Ammonia Emission Reductions

Ammonia emission reductions can include litter amendments like alum that suppress the formation of ammonia from ammonium in litter, biofilters attached to animal enclosure ventilation systems that detoxify ammonia, or lagoon covers that prevent volatilization from loss due to wind.

Costs are based on EQIP estimates and a study from Moore (2005). To convert EQIP estimates from dollars per square feet to dollars per AU, EPA assumes that 25,000 chickens would be housed in buildings 16,000 square feet in size (U.S. EPA, 2001a). Annual costs represent capital costs annualized over 10 years, or the reported annual costs of the practice, depending on the study.

Animal Waste Management Systems

Animal waste management systems involve controls designed for proper handling, storage, and utilization of wastes generated from confined animal feeding operations (CAFOs). This typically includes a means of collecting, scraping, or washing wastes from confinement areas into appropriate waste storage structures such as lagoons, ponds, or tanks for liquid wastes, and storage sheds or pits for solid wastes.

The animal waste management system costs represent estimates from actual systems installed in Virginia in 2009 and 2010 (VA DCR, 2011a). To provide consistent units from which to estimate costs associated with Phase II WIPs, EPA converts all cost estimates into dollars per animal units (AUs) per year. For this analysis, 1 AU equals 0.74 dairy cows, 1.14 beef cow, 2.67 to 9.09 hogs, 250 layers, 455 broilers, or 67 turkeys. (Costs can also be converted into dollars per manure acre by assuming 1 manure acre equals 145 AUs.) EPA annualizes capital costs over the specified life of the BMP (5 to 15 years, with 10 years being the most typical life of the BMP reported in the studies), and assumes annual O&M equal to 5% of BMP installation costs to estimate total annual costs.

Because the exact control mechanisms are not specified in the project list, it is difficult to determine the factors driving the unit costs.

Barnyard Runoff Controls

Barnyard runoff controls involve controlling runoff from barnyard areas (e.g., roof runoff control, diversion of clean water from entering the barnyard). Because barnyard runoff controls primarily target reductions in sediment loads, which are not necessarily related to the presence or type of animal on a farm, EPA develops unit costs in terms of dollars per system per year first and then converts these costs into dollars per acre per year for multiplication by the units in the inputs. To estimate annual costs, EPA annualizes capital costs over 15 years (EQIP practice life), assuming no annual O&M costs.

Unit cost estimates for barnyard runoff controls reflect three data sources:

- VA NRCS (2011) – provides estimates for typical project sizes based on average unit costs for various system components.
- MDA (2012) – estimates unit costs a single system based on past experience.
- DE CIW (2010) – provides unit costs in linear feet and the length (in feet) of an average system.

To develop the conversion factor for converting from dollars per system to dollars per acre, EPA uses values reported in the Delaware and New York WIPs and the corresponding credited acres used as input in the CBWM. For example, the Delaware WIP provides a goal of installing 120 systems by 2025, which corresponds to 181 acres in the CBWM, or an average of 1.5 acres/barnyard runoff control system. For New York, the average is 0.95 acres/structure based on information in the WIP that 1,000 dairy farms would install barnyard runoff, corresponding to 948 acres in the CBWM. The average value for the two states is 1.23 acres per structure.

Capture and 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. Water can then be recirculated for irrigation on other vegetation capable of trapping nutrients.

EPA estimates costs for capture and reuse based on MDA (2012) and annualizes the costs over the useful life of the equipment (10 years).

Carbon Sequestration and Alternative Crops

Carbon sequestration and alternative crops involve the conversion of cropland to hay land (warm season grasses) in which the hay land is managed as permanent, providing a mechanism for sequestering carbon within the soil.

Turhollow (2000) provides estimates of potential unit costs for carbon sequestration as described in EPA's 2003 Use Attainability Analysis (UAA) document. The costs include establishment, maintenance, harvest, transportation, and installation based on an average yield rate of five tons per acre per year. EPA (2003) estimates a potential for revenue from annual sale of biomass as a fuel source for a co-fired coal and biomass generator, value of CO_2 credits for replacing fossil fuel with biomass fuel, and value of CO_2 credits for additional soil carbon sequestration to range from $229/acre to $261/acre. Unit costs minus installation are approximately $260/acre. Because this is not a contractual BMP, there is no reason to expect a farmer to incur annual harvest and transportation costs if the fuel sales and CO_2 credits for fuel-switching do not offset annual costs. Therefore, EPA estimates that the maximum cost for this BMP is the installation cost, annualized over 10 years.

Commodity and Small Grains Cover Crops

Commodity and small grains cover crops are cover crops that may be harvested for grain, hay, or silage and receive nutrient applications after March 1 of the spring following establishment. The difference in costs from traditional cover crops is the additional revenue farmers may receive from harvesting the crops. Due to a lack of revenue data on harvested crop values for these types of crops, EPA uses the average of the cost share payments from the Delaware and Virginia EQIP programs as an estimate of the average annual unit cost for commodity cover crops.

Conservation Plans

Conservation plans consist of a 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. Note, that implementation of conservation plans may include a number of various BMPs, the combination of which is likely to be farm-specific.

Most of the WIPs refer to conservation plans as Soil Conservation and Water Quality Plans. EPA estimates unit costs for all jurisdictions based on an estimate from the Maryland Phase I WIP by dividing total estimated costs by estimated acres of implementation (MDE, 2010). To estimate annual costs, EPA annualizes the per acre cost over 10 years (useful life of plan).

Conservation Tillage

Conservation tillage involves 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.

Boyle (2006) indicates that conservation tillage is profit neutral. Thus EPA set costs equal to zero.

Continuous No-Till

Continuous no-till farming consists of crop planting and management practices in which soil disturbance by plows, disk, or other tillage equipment is eliminated. Continuous no-till involves no-till methods on all crops in a multi-crop, multi-year rotation.

Boyle (2006) indicates that conservation tillage is profit neutral. Thus EPA set costs equal to zero.

Cover Crops

Cover crops involve the planting and growing of cereal crops (non-harvested) with minimal disturbance of the surface soil. Different species are accepted for credit as well as, different times of planting (early, late, and standard), and fertilizer application restrictions. The estimated unit costs for various combinations of planting times (early, late, and standard), planting methods (drilled, aerial, and other), and crop types (rye, rye on soy, rye on corn, barley, barley on soy, barley on corn, wheat, wheat on soy, and wheat on corn).

EPA develops jurisdiction-specific estimates based on EQIP program costs for various cover crops and planting seasons. Based on information in Weiland et al. (2009), EPA assumes that the opportunity cost of the land used in this practice to be zero since cover crops are typically planted on land that would have otherwise lain fallow.

Cropland Irrigation Management

Cropland irrigation management is a practice that 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.

To estimate unit costs, EPA relies on EQIP payment information on irrigation water plans in Delaware, Pennsylvania, and Virginia, as well as the Maryland Phase I WIP, which provided estimates of total costs and practice implementation acres. For the EQIP costs, EPA estimates unit costs annualizing over3 years, and adds annual implementation costs. The Maryland Phase I WIP estimates include a capital component for irrigation equipment. Thus, EPA annualizes the Maryland costs over 15 years (useful life of irrigation equipment).

Dairy Precision Feeding

Dairy precision feeding reduces the quantity of phosphorous and nitrogen fed to livestock by formulating diets within 110% of Nutritional Research Council (NRC) recommended level to minimize the excretion of nutrients without negatively affecting milk production.

A number of studies indicate that dairy precision feeding results in a net cost savings to the farmer from a reduction in feed costs. However, because the CBPO definition indicates that feed levels must be within 110% of NRC recommended levels, EPA only uses data from studies indicating such. For example, Cerosaletti et al. (2004) conducted two different feed experiments, and found cost savings associated with precision feeding of $72 per cow per year and $7.30 per cow per year. However, the first experiment used forages that contained phosphorus levels that were higher than 110% of NRC recommended levels; additional phosphorus reductions would have increased total costs. Thus, EPA only uses the results indicating savings of $7.30 per cow per year.

EPA converts unit costs to AUs assuming 0.74 dairy cows per AU. EPA assumes all unit costs are annual.

Decision Agriculture

Decision agriculture is described as an information and technology based management system that is site specific and uses data on one or more of the following: soils, crops, nutrients, pests, moisture, or yield for optimum profitability, sustainability, and protection of the environment.

Decision agriculture encompasses a broad range of potential activities and can vary based on farm-specific characteristics. EPA uses unit costs of this practice from Pennsylvania EQIP, the Delaware Phase I WIP, and the Maryland Phase II WIP. The Pennsylvania and Delaware estimates are in dollars per acre per year. However, the Maryland estimate is for the capital cost associated with GPS equipment and is annualized over 5 years (useful life of GPS equipment).

Enhanced Nutrient Management

Enhanced nutrient management is nutrient management in which the nutrient management rates of nitrogen application are optimized to minimize excess fertilizer while maintaining crop yields (i.e., set 35% higher than crop needs to ensure nitrogen availability under optimal growing conditions). Farmers may receive an incentive and/or crop insurance payment to cover the risk of yield loss. However, given the potential economic benefit to the farmer and practice’s increased use in the watershed such incentives may not be necessary under the TMDL. MDA (2012) estimates enhanced nutrient management costs of $10 per acres. Because nutrient management plans typically last for 3 years, EPA annualizes costs over 3 years to estimate annual costs. Total enhanced nutrient management costs represent the cost of a regular nutrient management plan plus the additional payments associated with the practice.

Forest Buffers

Forest buffers are linear wooded areas along rivers, stream, and shorelines. The recommended buffer width for riparian forest buffers (agriculture) is 100 feet, with a 35-foot minimum width required. Upfront installation costs associated with forest buffers typically include site preparation, tree planting and replacement planting, tree shelters, initial grass buffer for immediate soil protection, mowing (during the first 3 years), and herbicide application (during the first three years).

EPA develops jurisdiction-specific unit costs based on EQIP data from Maryland, New York, and Pennsylvania; two studies described in EPA’s 2003 UAA document (Hairston-Strang, 2002; and MDA, 2002); average installation and land rental costs from the Delaware Phase I WIP (DE CIW, 2010); and average total installation costs across various individual projects reported in the Virginia BMP and CREP Query Tool. To estimate total annual costs, EPA annualizes upfront installation costs at over 75 years (useful life of buffers based on MD DNR, 1996), and adds annual opportunity/land rental costs to account for land taken out of production. For sources that do not include estimates of opportunity costs, EPA uses the average annual opportunity/land rental costs from sources that provide such information.

Grass Buffers

Grass buffers are 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 grass buffers (agriculture) is

100 feet, with a required minimum of 35 feet. Upfront installation costs associated with grass buffers typically include seed, fertilizer and lime, and labor and equipment associated with seed and fertilizer application.

EPA develops jurisdiction-specific unit costs based on EQIP data from Maryland, New York, Pennsylvania, Virginia, and West Virginia and average installation and land rental costs from the Delaware Phase I WIP (DE CIW, 2010). To estimate total annual costs, EPA annualizes upfront installation costs over 10 years (useful life of buffers based on MD DNR, 1996) and added annual opportunity/land rental costs to account for land taken out of production. For sources that do not include estimates of opportunity costs, EPA uses the average annual costs from those sources.

Horse Pasture Management

Horse pasture management involves stabilizing overused small pasture containment areas (animal concentration area) adjacent to animal shelters or farmstead. Simpson and Weammert (2009) indicate that horse pasture management involves maintaining a 50% pasture cover with managed species and managing high traffic areas. They also specify that animal trails and walkways and heavy use protection must be implemented in combination with either pasture and hayland planting or prescribed grazing.

To estimate average costs for this BMP, EPA uses information from VA NRCS (2011) and New York's Phase I WIP (NYSDEC, 2010). VA NRCS (2011) provides information on average installation size and unit costs for each component (animal trails and walkways, heavy use protection, pasture and hayland planting, and prescribed grazing) and estimated costs for various combinations of control scenarios:

- Animal trails and walkways with pasture and hayland planting
- Animal trails and walkways with prescribed grazing
- Heavy use protection with pasture and hayland planting
- Heavy use protection with prescribed grazing.

EPA estimates the average total cost across the scenarios, and annualizes over the estimated useful life (15 years) to estimate annual costs. EPA converts unit costs in dollars per system per year to dollars per acre per year using a typical pasture size in VA of 120 acres.

NYSDEC (2010) reports capital unit costs in dollars per acre and O&M costs in dollars per acre per year. To estimate annual costs, EPA annualizes capital over 15 years, and adds O&M.

Land Retirement

Land retirement is a practice that takes marginal and highly erosive cropland out of production by planting permanent vegetative cover such as shrubs, grasses, and/or trees.

Unit costs for land retirement represent the cost of planting the permanent cover as well as opportunity costs associated with taking land out of production. Note that farmers could also allow native cover to regrow but this could take several years and, thus, delay benefits of taking the land out of production. Thus, EPA assumes that costs include planting of permanent cover.

The Maryland Phase I WIP (MDE, 2010) contains estimates of total costs and total acres in which the state plans to implement land retirement. EPA estimates unit costs for all jurisdictions by dividing total costs by implementation acres. EPA assumes that the estimated cost includes opportunity/land rental costs associated with taking land out of production because the unit cost is slightly higher than the estimated unit costs for grass buffer, which also include opportunity costs. EPA annualizes the costs over 10 years (the length of a typical land retirement contract; other assumptions may be more appropriate under a regulatory framework).

Liquid Manure Injection

Manure injection is the subsurface application of manure from cattle, swine, or poultry. This practice reduces nutrient losses for both surface runoff and ammonia emissions. However, this practice is not appropriate for tillage incorporation or other post surface application incorporation methods.

Cost data are limited for this practice. EPA uses EQIP payment information on waste utilization injection in Maryland to estimate potential unit costs.

Loafing Lot Management

Loafing lot management is the 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. This BMP does not include poultry pad installation.

EPA estimates unit costs based on data from the Virginia BMP and CREP Query Tool (VA DCR, 2011b), which provides data on total project costs and the number of acres of BMP installed from which to calculate unit costs for each project and average unit costs across all projects. EPA annualizes project costs over 10 years (life of project specified in the query tool).

Manure Transport

Manure transport is a practice in which 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.

Unit costs vary based on the amount of manure transported and the travel distance (e.g., trucking and fuel costs). EPA uses estimates of average unit costs for system types (e.g., lagoon, slurry, and dry) and hauling methods (USDA, 2003). EPA escalates costs based on the change in price of diesel gas ($1.42/gal in 2003 to $3.89/gal in 2011) using the Retail On-Highway Diesel Price Index compiled by the Bureau of Transportation Statistics. For transport of manure within the watershed, EPA assumes a travel distance of 5.5 miles, and for transport outside of the watershed EPA assumes a travel distance of 40 miles. The units are in dollars per wet ton per year.

Mortality Composting

Mortality composting involves a physical structure and process for disposing of dead livestock. Farmers combine the composted material with poultry litter and land apply the materials based on nutrient management plan recommendations.

All unit costs are based on EQIP payment schedules from Pennsylvania, New York, Virginia, and West Virginia. EPA converts unit costs from EQIP in dollars per square feet of capacity into dollars per AU based on mortality rates for each animal type (e.g., 0.75% for dairy cow, 5% for layers, 14% for broilers and turkeys, 3% for nursery pigs, and 3.5% for breeding pigs), a depth of 5 feet (U.S. EPA, 2001), specific animal weights (e.g., 1400 lbs for dairy, 2 lbs for layers, 4 lbs for broilers, 15 lbs for turkeys, 40 lbs for nursery pigs, and 160 lbs for breeding pigs), and dead animal volume per pound (e.g., 20 ft^3/lb for dairy, 2 ft^3/lb for poultry, and 10 ft^3/lb for swine). EPA annualizes capital costs over 10 years.

Non-urban Stream Restoration

Non-urban stream restoration involves collection of site-specific engineering techniques used to stabilize an eroding streambank and channel. These are areas not associated with animal entry.

Jurisdiction-specific costs for Pennsylvania and West Virginia reflect unit costs from EQIP programs and estimate for Maryland are from the state's Phase I WIP, calculated by dividing total estimated costs by estimated acres of implementation (MDE, 2010). Costs for the remaining jurisdictions represent the average of the above estimates. To estimate annual per feet costs, EPA annualizes total project costs over 20 years.

Nutrient Management

Nutrient management consists of a comprehensive plan that describes the optimum use of nutrients to minimize nutrient loss while maintaining yield. A nutrient management plan details the type, rate, timing, and placement of nutrients for each crop, as determined through soil, plant tissue, manure, and/or sludge testing to assure optimal application rates.

EPA develops jurisdiction-specific nutrient management costs based on EQIP unit costs for plan development and implementation from all six Bay states. Where necessary, EPA annualizes costs over 3 years (life of plan; retesting is necessary to ensure proper nutrient management approximately every 3 years) to obtain annual unit costs. To account for potential cost savings resulting from decreased fertilizer use, EPA subtracts estimates from VA SWCD (2008).

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.

EPA bases unit costs on a study by Baker and Augspurger (2007) which reports costs in dollar per ton of feed and a report from the Chesapeake Bay Commission (2004) that provides annual costs in dollar per animal unit. To convert to dollars per AU, EPA assumed 0.00516 ton of feed per poultry lifetime (Angle, 2004) and 0.34 ton of feed per swine lifetime (Walker, 1992) and that the average broiler lifetime is 7 weeks (Jacob and Mather, 1998) and the average swine lifetime is 24 weeks from farrow to finisher (USDA, 2009).

Precision Intensive Rotational Grazing

Precision intensive rotational grazing is a practice that 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. This practice can be applied to pastures intersected by streams or upland pastures outside of the degraded stream corridor (35 feet width from top of bank). It also requires intensive management of livestock rotation, also known as Managed Intensive Grazing systems (MIG), that have very short rotation schedules.

Unit costs for this practice represent the average of EQIP costs from Delaware, Maryland, and West Virginia.

Prescribed Grazing

Prescribed grazing is a practice that utilizes a range of pasture management and grazing techniques to improve the quality and quantity of the forages grown on pastures and reduces the impact of animal travel lanes, animal concentration areas, or other degraded areas. Prescribed grazing can be applied to pastures intersected by streams or upland pastures outside of the degraded stream corridor (35 feet width from top of bank).

Unit costs represent the average of EQIP costs from all six Bay states. To annualize costs, EPA assumes that planning occurs over a 3 year period.

Tree Planting

Tree planting involves planting any tree, except those used to establish riparian forest buffers, that target highly erodible areas or those identified as critical resource areas.

Costs for Delaware, Pennsylvania, Virginia, and West Virginia are based on unit costs from state EQIP programs. Where EQIP costs are given in units of dollar per tree or seedling, EPA assumes that farmers would plant approximately 200 trees per acres to convert all costs into units of dollars per acre. To convert costs to an annual basis, EPA annualizes total per acre costs over 75 years (useful life of trees based on MD DNR, 1996) and adds an opportunity cost associated with taking land out of production.

For Maryland, the tree planting BMP in the watershed model represents vegetative environmental buffers on poultry operations. EPA annualizes practice costs over 10 years and does not include the estimate in the average calculation for states without EQIP estimates as described above.

Water Control Structures

Water control structures involve installing and managing boarded gate systems in agricultural land that contains surface drainage ditches.

EPA develops unit costs for all jurisdictions based on typical project sizes and average unit costs in Virginia (VA NRCS, 2011). Total annual costs represent upfront installation costs annualized over 10 years (typical EQIP practice life). To develop the conversion factor to convert from dollars per system to dollars per acre, EPA uses MDA (2012) estimate of 29 acres per water control structure.

Wetland Restoration

Wetland restoration involves activities that reestablish 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.

EPA develops unit costs for Maryland and Pennsylvania based on costs from EQIP programs and unit costs for New York based on the state's Phase I WIP (NYSDEC, 2010). Costs for the remaining states represent the average of the above three estimates. Total annual costs represent upfront installation costs annualized over 15 years (typical EQIP practice life) plus annual opportunity costs (based on state land rental payments for the practice).

Resource Practices

Exhibit 2 summarizes the unit cost of the four principal BMPs that address the resource practices source category. The practices are described below.

Exhibit 2: Unit Costs for Resource Practices (2010$)

BMP	Average Annual Unit Costs								Units
	Average	DC	DE	MD	NY	PA	VA	WV	
Abandoned Mine Reclamation	$615	NA	NA	NA	NA	$615	NA	NA	$/acre/yr
Forest Harvesting	$64	NA	NA	NA	NA	$97	$31	NA	$/acre/yr
Extractive Erosion and Sediment Control	$145	NA	NA	NA	NA	NA	NA	NA	$/acre/yr
Road Erosion and Sediment Control	$1	NA	NA	NA	NA	$1	NA	NA	$/feet/yr

NA = Not available.

Abandoned Mine Reclamation

Abandoned mine reclamation stabilizes the soil on lands mined for coal or affected by mining, such as wastebanks, coal processing, or other coal mining processes. The practice affects the distribution of pervious and impervious areas modeled (USEPA, 2010).

EPA derives unit costs for this practice based on Pennsylvania Department of Environmental Protection (PADEP, 2004), which provides capital and O&M unit costs on a per acre basis, and annualizes capital costs over a 20-year useful life.

Dirt and Gravel Road Erosion and Sediment Control

Dirt and gravel roads, such as roads that provide access to sites used for logging or other resource practices activity, are an important source of sediment to the Bay. This is because unimproved roads often lack stormwater management controls to minimize erosion impacts to local streams during severe rainfall events, resulting in fully erosion and high sediment loads to streams. Such roads are particularly prevalent in rural areas of the Ridge & Valley, Piedmont, and Allegheny Plateau (CBP, 2011).

The CBWM provides credits for measures aimed at reducing the amount of sediment runoff from dirt and gravel roads through the use of driving surface aggregates (DSA), berm removal, additional drainage outlets, raising the road profile, and grade breaks. The model defines three specific practices (Scheetz and Bloser, 2008):

- *Driving Surface Aggregate and Raising the Roadbed*, which involves using durable and erosion resistant road surface[1] and raising the road elevation to restore natural drainage patterns;
- *Driving Surface Aggregate and Raising the Roadbed, with Outlets*, which involves, in addition to the measures above, creating new outlets in ditch to reduce channelized flow reaching a stream[2]; and
- *Outlets only*, which involves adding drainage outlets alone, without changes to the driving surface or regarding of the roadbed.

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[1] The durability comes from using an aggregate distribution that is specifically designed for use as road surface. In addition to being less susceptible to erosion and associate pollutant runoff, the use of this mixture reduces long-term maintenance costs.

[2] Installing additional drainage outlets reduces concentrated flow, peak flow discharges and sediment transport and delivery from unpaved roads and ditches into streams, and can increase infiltration (Klimkos and Scheetz, 2009).

PADEP (2004) provide a general cost estimate for erosion and sediment control. For this analysis, EPA assumes that the capital costs of all three sub-practices listed above are the same: $10.39 per linear foot (in 2010 dollars) and annualizes these costs over 20 years.

Extractive Erosion and Sediment Control

Extractive erosion and sediment control measures are implemented mainly on mining lands. This practice is not defined in the most recent documentation for the CBWM, but may include activities such as regrading mine spoils/highwalls or revegetation. For this analysis, EPA estimates control costs based on EPA's BMP guidance manual for coal remining (USEPA, 2000), annualizing over 10 years (the assumed average life of a mine), updating to 2010 dollars using the CPI.

Forest Harvesting Practices

Commercial tree harvest operations disturb ground cover, expose mineral soil, and open the forest floor to rainfall.

The CBWM provides credits for measures aimed at reducing sediment and nutrient pollution to water bodies originating from forest harvesting activities at managed levels. The model defines forest harvesting practices as a suite of BMPs that minimize the environmental impacts of road building, log removal, site preparation and forest management.

EPA uses unit costs for these practices from PADEP (2004) and Weiland et al. (2009). Costs presented in Weiland et al. (2009) are based on forest harvesting practices implemented in Virginia and represent the average of coastal and Piedmont unit costs. EPA escalates the costs from the 2004 and 2007 dollars used in the two sources, respectively, to 2010 dollars using the CPI. Costs for other jurisdictions in the Bay represent the average of the two states.

Urban Stormwater

Impervious surfaces in urban areas, like roads, rooftops, and parking lots, channel stormwater runoff directly to streams, tributaries and to the Bay by preventing infiltration into the ground. This runoff carries with it heavy loads of nutrients and sediments. Runoff from developed land (urban and suburban) was responsible for approximately 8% of the total nitrogen, 14.5% of the total phosphorus and 15.9% of the total sediment load into the Bay in 2009 (NAS, 2011).

The TMDL seeks to cap total nitrogen loads from urban runoff to 15.6 million pounds, total phosphorus to 1.7 million pounds, and total sediment to 798 million pounds per year.

To achieve this goal, Bay jurisdictions have developed strategies that include measures aimed at reducing the amount of pollutants carried with the runoff (e.g., reduction in fertilizer application), measures aimed at reducing or controlling the runoff (e.g., use of bioretention, impervious surface reduction, and wet ponds), and measures aimed at improving the natural filtering capacity of tributaries in urban areas (e.g., stream restoration).

EPA uses unit costs for most urban stormwater practices from the Center for Watershed Protection (CWP, 2007) and EPA updates construction costs using the ENR construction cost index (CCI; 2006 = 7751, 2010 = 8802). The costs include the capital costs for construction, design and engineering costs (calculated as a percent of construction costs), costs for ongoing operation and maintenance (typically calculated as a percent of construction costs), and land opportunity costs, where applicable. The costs represent dollars per impervious acre of land treated. Because the acre basis used to specify the level of implementation in the Phase II WIPs is either the acres covered by the control or the total acres treated (e.g., acres over which forest buffers are installed or acres of turf with reduced fertilizer),[3] EPA uses conversion factors provided in King and Hagan (2011) (e.g., 3.7 acres of urban grass buffer treat 1 impervious acres of land). To convert impervious acres treated to total acres treated, EPA multiplies the unit costs by the percent of impervious urban land in each jurisdiction, based on land use acres from the 2010 No Action Phase 5.3 model run (shown in **Exhibit**3).

Exhibit 3: Percent Impervious Urban Land in Bay Jurisdictions

Jurisdiction	Percent of Urban Land that is Impervious
Total Watershed	25.9%
District of Columbia	51.3%
Delaware	24.3%
Maryland	25.3%
New York	27.0%
Pennsylvania	25.4%
Virginia	26.2%
West Virginia	25.3%

EPA annualizes upfront capital costs (construction and design and engineering) over the estimated useful life of each practice, using a 5% discount rate. EPA uses this same 5% discount rate to annualize land opportunity costs, but treating land as an asset without a finite life (i.e., perpetuity). For the analysis discussed below, EPA assumes default land costs of $100,000 per impervious acre. EPA calculates annual unit cost per impervious acre of each control by summing the annualized capital and land opportunity costs and the O&M costs, and then converts to dollars per acres treated or BMP installed as described above.

Exhibit4 summarizes available costs for the urban stormwater management practices credited to the Bay jurisdictions. The following sections describe the derivation of unit costs for each practice.

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[3] See uncertainty section for a discussion of the basis assumed for acres

Exhibit 4: Summary of Annual Unit Costs for Urban Stormwater Controls (2010$)[1]

Chesapeake Bay WIP Practices	Annual Unit Costs								Units
	Average	DC	DE	MD	NY	PA	VA	WV	
New/Redevelopment									
Bioretention	$875	$1,733	$822	$856	$913	$858	$884	$854	$/acre treated/yr
Bioswale	$704	$1,395	$662	$689	$735	$690	$712	$688	$/acre treated/yr
Dry Detention and Extended Detention Basins	$196	$387	$184	$191	$204	$192	$198	$191	$/acre treated/yr
Dry Detention Ponds/Hydrodynamic Structures	$775	$1,535	$728	$759	$809	$760	$783	$757	$/acre treated/yr
Erosion and Sediment Control	$540	$1,070	$508	$529	$564	$530	$546	$527	$/acre treated/yr
Urban Tree Planting	$65	NA	$12	$85	NA	$108	$53	$70	$/acre treated/yr
Urban Filtering Practices	$2,371	$4,697	$2,228	$2,321	$2,475	$2,325	$2,397	$2,315	$/acre treated/yr
Urban Infiltration Practices	$865	$1,713	$812	$846	$902	$848	$874	$844	$/acre treated/yr
Vegetated Open Channels	$835	$1,654	$785	$818	$872	$819	$844	$815	$/acre treated/yr
Wetlands and Wet Ponds	$201	$398	$189	$197	$210	$197	$203	$196	$/acre treated/yr
SWM by Era	$0	NA	NA	$1,547	NA	NA	NA	NA	$/acre treated/yr
Retrofit of Existing Development									
Bioretention	$1,286	$2,548	$1,209	$1,259	$1,342	$1,261	$1,300	$1,256	$/acre treated/yr
Bioswale	$1,062	$2,104	$998	$1,040	$1,109	$1,041	$1,074	$1,037	$/acre treated/yr
Dry Detention and Extended Detention Basins	$503	$997	$473	$493	$525	$494	$509	$491	$/acre treated/yr

Exhibit 4: Summary of Annual Unit Costs for Urban Stormwater Controls (2010$)[1]

Chesapeake Bay WIP Practices	Annual Unit Costs								Units
	Average	DC	DE	MD	NY	PA	VA	WV	
Dry Detention Ponds/Hydrodynamic Structures	$775	$1,535	$728	$759	$809	$760	$783	$757	$/acre treated/yr
Impervious Surface Reduction	$14,214	$14,214	$14,214	$14,214	$14,214	$14,214	$14,214	$14,214	$/acre installed/yr
Retrofit Stormwater Management	$1,000	NA	NA	$1,000	NA	NA	NA	NA	$/acre treated/yr
Urban Tree Planting	$65	NA	$12	$85	NA	$108	$53	$70	$/acre installed/yr
Urban Filtering Practices	$2,371	$4,697	$2,228	$2,321	$2,475	$2,325	$2,397	$2,315	$/acre treated/yr
Urban Forest Buffers	$86	NA	$27	$92	$121	$153	$35	NA	$/acre installed/yr
Urban Grass Buffers	$47	NA	$39	$56	$36	$68	$45	$37	$/acre installed/yr
Urban Infiltration Practices	$1,366	$2,705	$1,283	$1,337	$1,425	$1,339	$1,381	$1,333	$/acre treated/yr
Vegetated Open Channels	$835	$1,654	$785	$818	$872	$819	$844	$815	$/acre/yr
Wetlands and Wet Ponds	$473	$937	$444	$463	$494	$464	$478	$462	$/acre treated/yr
Other[2]									
CSO Separation	$16,703	$16,703	NA	NA	NA	NA	NA	NA	$/acre/yr
Forest Conservation	$0	$0	$0	$0	$0	$0	$0	$0	$/acre installed/yr
Street Sweeping	$916	NA	NA	NA	NA	NA	NA	NA	$/acre installed/yr

Exhibit 4: Summary of Annual Unit Costs for Urban Stormwater Controls (2010$)[1]

Chesapeake Bay WIP Practices	Annual Unit Costs								Units
	Average	DC	DE	MD	NY	PA	VA	WV	
Urban Nutrient Management	$19	NA	NA	NA	NA	NA	NA	NA	$/acre installed/yr
Urban Stream Restoration	$60	NA	NA	NA	NA	NA	NA	NA	$/feet installed/yr

1. Capital and land opportunity costs annualized at 5%.
2. Not applicable to new development/redevelopment, or no differentiation in unit costs between new development/redevelopment available.

Bioretention

Bioretention involves an excavated pit backfilled with engineered media, topsoil, mulch, and vegetation. These practices are planting areas installed in shallow basins in which the storm water runoff is temporarily ponded and then treated by filtering through the bed components, and through biological and biochemical reactions within the soil matrix and around the root zones of the plants.

The watershed model inputs are in units of the acres treated per year. EPA uses unit costs for bioretention from the CWP (2007), who estimated average costs for new installations and retrofits in dollars per acre of impervious surface treated by the control per year. EPA annualizes construction costs over 25 years. EPA calculates average annual O&M costs as 2.5% of new installation capital costs (EPA, 2011). EPA includes opportunity cost for land assuming that the planted area occupies 6% of the impervious acres treated by the control, of which 50% are developable (King and Hagan, 2011).

Since this practice is designed to treat total runoff from a site, however, EPA converts the total annual unit costs on a per impervious acre basis into costs per total acres treated using the average fraction of impervious acres within the urban land uses in each jurisdiction, as described above.

Bioswale

Bioswales typically consist of a swaled drainage course with gently sloped sides that are filled with vegetation, compost, and/or riprap. With a bioswale, the load is reduced because, unlike other open channel designs, there is treatment through the soil. A bioswale is designed to function as a bioretention area.

The watershed model inputs are in units of the acres treated per year. EPA uses unit costs for bioswales from the CWP (2007), who estimated average costs for new installations and retrofits in dollars per acre of impervious surface treated by the control per year. EPA annualizes construction costs over 50 years (EPA, 2005). EPA calculates average annual O&M costs as 6% of new installation capital costs (EPA, 2011).EPA includes opportunity cost for land assuming that the planted area occupies 4% of the impervious acres treated by the control, of which 50% are developable (King and Hagan, 2011).

Since this practice is designed to treat total runoff from a site, however, EPA converts the total annual unit costs on a per impervious acre basis into costs per total acres treated using the average fraction of impervious acres within the urban land uses in each jurisdiction, as described above.

CSO Separation

CSO separation involves disconnecting the storm drain and overflow from the sanitary sewer system. Unit costs are based on estimates from the CSO long-term control plan for the District of Columbia.

Dry Extended Detention Ponds

Dry extended detention ponds are similar to dry detention ponds but are designed to detain stormwater for a longer period of time, thereby improving treatment effectiveness.

EPA uses unit costs from CWP (2007) expressed in dollars per impervious acres treated, and annualizes over the estimated 50-year life of the control (USEPA, 2005) EPA calculates annual O&M costs as 5% of capital costs (King and Hagan, 2011). EPA calculates land opportunity costs based on the fraction of impervious land occupied by the pond (10%), and the fraction developable (50%; King and Hagan, 2011).

Finally, EPA converts the unit costs on a per impervious acre basis into costs per total acres treated using the average fraction of impervious acres within the urban land uses in each jurisdiction, as described above.

Dry Detention Ponds and Hydrodynamic Structures

Dry detention basins are depressions or basins created by excavation or berm construction that temporarily store runoff and release it slowly via surface flow or groundwater infiltration following storms and that are designed to dry out between storm events. The basins do not typically contain vegetation like bioretention and bioswales. Hydrodynamic structures are devices designed to improve quality of stormwater using features such as swirl concentrators, grit chambers, oil barriers, baffles, micropools, and absorbent pads that are designed to remove sediments, nutrients, metals, organic chemicals, or oil and grease from urban runoff (USEPA, 2010).

EPA uses estimated unit costs of the two BMPs from King and Hagan (2011) expressed on a per impervious acre basis. The estimates are based on the average of costs reported separately for dry detention ponds and hydrodynamic structures. EPA annualizes the pre-construction and construction costs over 50 years. EPA estimates annual O&M costs as the average of the two practices, based on 2% of new installation capital costs (EPA, 2011). EPA calculates the land opportunity costs assuming that the control occupies 10% of the impervious land area treated, of which 50% is developable (King and Hagan, 2011).

Finally, EPA converts the unit costs on a per impervious acre basis into costs per total acres treated using the average fraction of impervious acres within the urban land uses in each jurisdiction, as described above.

Erosion and Sediment Control

Erosion and sediment control practices are measures to protect water resources from sediment pollution and increases in runoff associated with land development activities. By retaining soil on-site, sediment and attached nutrients are prevented from leaving disturbed areas and polluting streams (USEPA, 2010).

EPA uses estimated unit costs for this practice from King and Hagan (2011), who estimated average costs based on a typical 14-acre development project involving silt fences, sediment ponds, and related practices. EPA assumes the costs represent the dollar per acre treated. EPA annualizes pre-construction and construction costs over 20 years.

Forest Conservation

Forest conservation currently only applies to Maryland where it represents the implementation of the Maryland Forest Conservation Act that requires developers to maintain at least 20% of a development site in trees (forest condition) (USEPA, 2010).

Because this practice involves keeping existing forests, EPA assumes that it imposes no incremental capital or O&M costs (e.g., any lost development opportunity for this practice is offset by cost savings).

Impervious Urban Surface Reduction

As the name implies, impervious urban surface reduction involves reducing existing impervious area of urban development to facilitate infiltration and reduce stormwater runoff.

EPA uses unit costs of this practice from CWP (2007), annualizing construction costs over the 20-year useful life. EPA calculates land opportunity costs assuming that 50% of acres used for the control are developable (King and Hagan, 2011). EPA then adds the annualized upfront costs to the annual O&M (calculated as 5% of construction costs) to estimate the total annual cost of this practice.

In applying cost estimates provided by CWP (2007), EPA assumes that half of the impervious surface is asphalt and half is concrete. To account for maintenance costs of these surfaces that would occur in the absence of reduction in these impervious surfaces, EPA subtracts half of the estimated asphalt and concrete maintenance costs from the O&M costs associated with impervious surface reduction since there is uncertainty regarding the type of land being replaced with a pervious surface. EPA assumes that concrete surfaces would not need maintenance, but that asphalt surfaces would need re-paving every 12 years at a cost of $2 to $3 per square foot, based on estimates from the City of Rockville (2010) and the Permeable Interlocking Pavement Institute (2012).

Retrofit Stormwater Management

EPA estimates costs of this practice by averaging costs for all practices for which retrofit unit costs are available.

Street Sweeping

In the watershed model, street sweeping includes both street sweeping and storm drain cleanout practices (USEPA, 2010). The model provides credits on for the two sub-practices on the basis of the frequency (“mechanical monthly”) or loading reductions (“pounds”).

EPA uses costs of this practice from King and Hagan (2011). The costs account for the purchase of street sweepers (average of mechanical and vacuum style equipment). EPA annualizes the capital costs over 20 years. Since the practice applies to impervious acres specifically, EPA does not make any further adjustment.

Urban Tree Planting

Urban tree planting involves planting trees on urban pervious areas at a rate that would produce a forest-like condition over time. The intent of the planting is to eventually convert the urban area to forest. If the trees are planted as part of the urban landscape, with no intention to convert the area to forest, then the planting would not count as urban tree planting (U.S. EPA, 2010).

Since the cost of tree planting is likely to be consistent across agricultural and urban areas, EPA uses jurisdiction-specific unit costs from EQIP. For EQIP costs in units of dollar per tree or seedling, EPA assumes approximately 200 trees per acres to convert to units of dollars per acre. To convert costs to an annual basis, EPA annualizes total per acre costs over 75 years (useful life of trees based on MD DNR, 1996). For this practice, EPA does not account for land costs, since planting trees can often increase the value of property through functional and aesthetic benefits (e.g. Nowak et al., 2002).

Urban Filtering Practices

Urban filtering practices are measures that capture and temporarily store runoff and pass it through a filter bed of either sand or an organic medium. There are various sand filter designs, such as aboveground, belowground, and perimeter designs. An organic media filter uses another medium besides sand to enhance pollutant removal for many compounds because of the increased cation exchange capacity achieved by increasing the organic matter. The systems require yearly inspection and maintenance to receive pollutant reduction credit (U.S. EPA, 2010).

The watershed model includes this control in total acres treated per year. EPA uses unit costs for these practices from the CWP (2007), who estimated average construction costs in terms of dollars per impervious acre filtered per year. EPA annualizes construction costs over 25 years. EPA estimates annual O&M costs as 5% of new installation capital costs. EPA includes opportunity cost for land assuming that the control occupies 5% of the impervious land treated, of which 50% is developable (based on King and Hagan, 2011).

Since this practice is designed to treat total runoff from a site, however, EPA converts the unit costs on a per impervious acre basis into costs per total acres treated (the units in the watershed model) using the average fraction of impervious acres within the urban land uses in each jurisdiction.

Urban Forest Buffers

Urban forest buffers involve planting an area of trees at least 35 feet wide on one side of a stream, usually accompanied by trees, shrubs and other vegetation that is adjacent to a body of water. The riparian area is managed to maintain the integrity of stream channels and shorelines, to reduce the impacts of upland sources of pollution by trapping, filtering, and converting sediments, nutrients, and other chemicals (USEPA, 2010).

EPA assumes that costs associated with establishing forest buffers in urban areas are comparable to those of establishing forest buffers in agricultural areas. EPA develops jurisdiction-specific unit costs based on EQIP data from Maryland, New York, and Pennsylvania; two studies described in EPA's 2003 UAA document (Hairston-Strang, 2002; and MDA, 2002); average installation and land rental costs from the Delaware Phase I WIP (DE CIW, 2010); and average total installation costs across various individual projects reported in the Virginia BMP and CREP Query Tool. To estimate total annual costs, EPA annualizes upfront installation costs over 75 years (useful life of buffers based on MD DNR, 1996). EPA does not adjust for land costs, since buffers are necessarily located adjacent to streams, which are unlikely to be developable due to zoning restrictions.

Urban Growth Reduction

Urban growth reduction is the change from forecast urban land use to non-urban land use (USEPA, 2010). Because this practice involves unknown land use changes in the future, EPA did not estimate incremental costs or benefits as they would be speculative. EPA anticipates that any increase in costs could be offset by cost savings through reduced needs for infrastructure or services.

Urban Infiltration Practices

Urban infiltration practices use a depression to form an infiltration basin where sediment is trapped and water infiltrates the soil. No underdrains are associated with infiltration basins and trenches, because by definition these systems provide complete infiltration. Design specifications require infiltration basins and trenches to be built in good soil; they are not constructed on poor soils, such as C and D soil types. Engineers are required to test the soil before approval to build is issued. To receive credit over the longer term, jurisdictions must conduct yearly inspections to determine if the basin or trench is still infiltrating runoff (USEPA, 2010).

The CBWM differentiates between those BMPs that use sand and/or vegetation and those that do not. BMPs with sand and/or vegetation are assumed to be slightly more effective at removing nitrogen (85% effectiveness vs. 80%).

The watershed model includes this practice in terms of total acres treated. EPA uses unit costs for these practices from the CWP (2007), who estimated average costs for infiltration basin construction in terms of impervious acres treated. EPA annualizes the construction cost over 50 years and adds the annualized value to the average O&M, which EPA estimates as 4% of new installation capital (EPA, 2011). EPA includes opportunity cost for land assuming that the control occupies 10% of the impervious land treated, of which 50% is developable (based on King and Hagan, 2011).

Finally, since this practice is designed to treat total runoff from a site, EPA converts the unit costs on a per impervious acre basis into costs per total acres treated (the units in the watershed model) using the average fraction of impervious acres within the urban land uses in each jurisdiction.

Urban Nutrient Management

Urban nutrient management involves public education (targeting urban/suburban residents and businesses) to encourage reduction of excessive fertilizer use. EPA's Nutrient Subcommittee's Tributary Strategy Workgroup has estimated that urban nutrient management reduces nitrogen loads by 17% and phosphorus loads by 22% (USEPA, 2010).

EPA estimates urban nutrient management costs based on average costs for soil test kits, assuming one test kit per household, and the median lot size for a house of 0.27 acres (according to Census data). To estimate annual costs, EPA annualizes the soil test kit cost over the life of the test results (3 years).

Urban Stream Restoration

This practice involves the restoration of the urban stream ecosystem by restoring the natural hydrology and landscape of a stream, to improve habitat and water quality conditions (USEPA, 2010).

The watershed model includes this practice in terms of linear feet of stream. EPA uses estimates for this practice from King and Hagan (2011), who estimate costs per impervious acre treated. EPA annualizes the pre-construction and construction costs over 20 years. EPA assumes that land opportunity costs are negligible as development is generally not allowed in close proximity to streams.

Since this practice is designed to apply specifically to buffers along urban streams, EPA converts the unit costs (expressed by King and Hagan on a per impervious acre basis) into costs per linear foot of stream restored (the units in the watershed model) assuming that 100 linear feet of restored stream treats 1 acre of impervious area (King and Hagan, 2011).

Vegetated Open Channels

Vegetated open channels are practices that convey stormwater runoff and provide treatment as the water is conveyed. Runoff passes through either vegetation in the channel, subsoil matrix, and/or is infiltrated into the underlying soils.

EPA uses the unit cost of this practice from King and Hagan (2011). EPA annualizes construction and preconstruction (estimated as a percent of construction costs) costs over 20 years. EPA estimates annual O&M costs as 6% of capital costs (EPA, 2011). EPA calculates land opportunity costs assuming that 50% of acres are developable and that 4% of the impervious land area treated by the control would be covered by the channel (King and Hagan, 2011).

Since this practice is designed to treat total runoff from a site, however, EPA converts the total annual unit costs on a per impervious acre basis into costs per total acres treated (the units in the watershed model) using the average fraction of impervious acres within the urban land uses in each jurisdiction, as described above.

Wet Ponds and Wetlands

Wet ponds and wetlands used as a BMP for managing urban stormwater runoff are man-made landscape features that have characteristics and functions similar to their natural counterparts. Wet ponds are depressions or basins created by excavation or berm construction that receive sufficient water via runoff, precipitation, and groundwater to contain standing water year-round at depths too deep to support rooted emergent or floating-leaved vegetation (in contrast with dry ponds, which dry out between precipitation events). Wetlands, on the other hand, have soils that are saturated with water or flooded with shallow water that support rooted floating or emergent aquatic vegetation (e.g. cattails). Some systems can contain submergent vegetation or emergent vegetation along the shorelines, blurring the distinction between the two (USEPA, 2010).

EPA uses unit costs for these controls from the CWP (2007), who estimated average costs for new installations and retrofits in dollars per impervious acre treated. EPA annualizes construction costs over 50 years (EPA, 2005) and calculates average annual O&M costs as 5% of new installation capital costs (EPA, 1999). EPA includes opportunity cost for land assuming that the control occupies 4% of the impervious land treated by the control, of which 50% are developable (King and Hagan, 2011). .

Since this practice is designed to treat total runoff from a site, however, EPA converts the total annual unit costs on a per impervious acre basis into costs per total acres treated (the units in the watershed model) using the average fraction of impervious acres within the urban land uses in each jurisdiction, as described above.

SWM by Era

Stormwater management by era accounts for underreporting of current progress in implementing urban controls in Maryland. Rather than reporting progress for individual urban practices, the jurisdiction defined stormwater management eras and estimated acreage controlled in each era. In the watershed model, each era is associated with a pollutant loading reduction efficiency for TN, TP, and sediment based on regulatory requirements during the period. To estimate unit costs for these controls, EPA uses the average unit cost of all controls for which new/redevelopment unit costs are available, and assumes that retrofits are included under the jurisdictions Retrofit Stormwater.

Attachment 5:

U.S. Environmental Protection Agency Approved Cost Efficiencies for Best Management Practices of Delivered TSS

(Draft – subject to change, do not quote or cite)

			Cost Per Pound Reduced		
Sector	**BMP**	**BMP Short Name**	**Low**	**Mid**	**High**
Ag	Poultry Litter Treatment (alum, for example)	**Alum**	-	-	-
Ag	Animal Waste Management System	**AWMS**	-	-	-
Ag	Barnyard Runoff Control	**BarnRunoffCont**	$0.41	$0.77	$5.48
Ag	Irrigation Water Capture Reuse	**CaptureReuse**	-	-	-
Ag	Alternative Crops	**CarSeqAltCrop**	$0.06	$0.09	$0.20
Ag	Heavy Use Poultry Area Concrete Pads	**ConcretePads**	$3.37	$11.67	$29.17
Ag	Soil Conservation and Water Quality Plans	**ConPlan**	$0.52	$1.88	$6.43
Ag	Conservation Tillage - Total Acres	**ConserveTollTotAcres**	$0.10	$0.88	$2.88
Ag	Cover Crop Standard Drilled Wheat	**CoverCropSDW**	$0.79	$16.81	-
Ag	Cropland Irrigation Management	**Cropirrmgmt**	-	-	-
Ag	Decision Agriculture	**DecisionAg**	$3.43	$6.86	$13.71
Ag	Sorbing Materials in Ag Ditches	**DitchFilter**	-	-	-
Ag	Enhanced Nutrient Management	**EnhancedNM**	$2.50	$5.00	$10.00
Ag	Forest Buffers	**ForestBuffers**	$0.16	$0.78	$2.65
Ag	Grass Buffers; Vegetated Open Channel - Agriculture	**GrassBuffers**	$0.25	$0.97	$1.56
Ag	Horse Pasture Management	**HorsePasMan**	$3.28	$46.15	$600.00
Ag	Land Retirement to hay without nutrients (HEL)	**LandRetireHyo**	$0.23	$0.73	$3.52
Ag	Land Retirement to pasture (HEL)	**LandRetirePas**	$0.10	$0.38	$1.13
Ag	Dairy Manure Incorporation	**LiquidInjection**	-	-	-
Ag	Loafing Lot Management	**LoafLot**	$1.13	$6.72	$91.55
Ag	Mortality Composters	**MortalityComp**	-	-	-
Ag	Non Urban Stream Restoration; Shoreline Erosion Control	**NonUrbStrmRest**	$3.34	$5.15	$5.31

Attachment 5:

U.S. Environmental Protection Agency Approved Cost Efficiencies for Best Management Practices of Delivered TSS (continued)

(Draft – subject to change, do not quote or cite)

			Cost per Pound Reduced		
Sector	**BMP**	**BMP Short Name**	**Low**	**Mid**	**High**
Ag	Nutrient Management	**NutMan**	$1.75	$3.50	$7.00
Ag	Off Stream Watering Without Fencing	**OSWnoFence**	$1.84	$5.90	$27.56
Ag	Stream Access Control with Fencing	**PastFence**	$0.02	$0.06	$0.46
Ag	Poultry Litter Incorporation	**PoultryInjection**	-	-	-
Ag	Poultry Phytase	**PoultryPhytase**	-	-	-
Ag	Prescribed Grazing	**PrecRotGrazing**	$2.09	$11.76	$85.71
Ag	Tree Planting; Vegetative Environmental Buffers — Poultry	**TreePlant**	$0.27	$2.05	$16.38
Ag	Precision Intensive Rotational Grazing	**UpPrecIntRotGraze**	$3.37	$7.32	$28.57
Ag	Water Control Structures	**WaterContStruc**	-	-	-
Ag	Wetland Restoration	**WetlandRestore**	$0.61	$1.66	$2.82
Manure	Manure Transport	**-**	-	-	-
Forest	Forest Harvesting Practices	**ForHarvestBMP**	$0.08	$0.22	$0.49
WWTP	Set Permitted Load	**WWLoadReduction**	-	-	-
Urban	Abandoned Mine Reclamation	**AbanMineRec**	-	-	-

Attachment 5:

U.S. Environmental Protection Agency Approved Cost Efficiencies for Best Management Practices of Delivered TSS (continued)

(Draft – subject to change, do not quote or cite)

			Cost per Pound Reduced		
Sector	**BMP**	**BMP Short Name**	**Low**	**Mid**	**High**
Urban	Bioretention/raingardens	**BioRetUDAB**	$2.15	$6.00	$16.72
Urban	Bioswale	**BioSwale**	$1.67	$7.55	$254.05
Urban	Dry Detention Ponds and Hydrodynamic Structures	**DryPonds**	$24.86	$100.08	$1,951.50
Urban	Erosion and Sediment Control	**EandS**	$0.36	$0.84	$2.12
Urban	Erosion and Sediment Control on Extractive, excess applied to all other pervious urban	**EandSext**	$1.20	$3.55	$8.70
Urban	Dry Extended Detention Ponds	**ExtDryPonds**	$2.55	$4.66	$87.44
Urban	Urban Filtering Practices	**Filter**	$3.50	$12.31	$252.63
Urban	Urban Forest Buffers	**ForestBufUrban**	$1.65	$4.22	$9.78
Urban	Forest Conservation	**ForestCon**	-	-	-
Urban	Impervious Urban Surface Reduction	**ImpSurRed**	$4.17	$13.53	$27.69
Urban	Urban Infiltration Practices - no sand\veg no under drain	**Infiltration**	$3.83	$9.60	$75.01
Urban	Urban Infiltration Practices - with sand\veg no under drain	**InfiltWithSV**	$3.19	$11.85	$17.37
Urban	Permeable Pavement w/ Sand, Veg. - A/B soils, underdrain	**PermPavSVUDAB**	$39.35	$73.67	$103.55
Urban	MS4 Permit-Required Stormwater Retrofit	**RetroSWM**	$4.10	$12.80	$256.01
Urban	Street Sweeping 25 times a year-acres (formerly called Street Sweeping Mechanical Monthly)	**StreetSweep**	$6.49	$24.62	$50.02
Urban	Urban Nutrient Management	**UrbanNutMan**	-	-	-
Urban	Urban Tree Planting; Urban Tree Canopy	**UrbanTreePlant**	$13.01	$29.63	$107.80
Urban	Urban Stream Restoration; Shoreline Erosion Control; Regenerative Stormwater Conveyance	**UrbStrmRest**	$13.02	$20.50	$31.64
Urban	Vegetated Open Channel - Urban	**VegOpChanNoUDAB**	$1.78	$4.87	$9.66
Urban	Wet Ponds and Wetlands	**WetPondWetland**	$2.27	$6.08	$130.32