Cost Analysis of Stormwater and Agricultural Practices for Reducing Nitrogen and Phosphorus Runoff in Maryland

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MDE Agreement # U00P8400697
UMCES #32133

UMCES Technical Report # TS-772-21
Ref. No. [UMCES] CBL 2021-064
(Revision of UMCES Technical Report #TS-730-19)

March 2021

University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE
CHESAPEAKE BIOLOGICAL LABORATORY

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Date: March 2021

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Appropriate Citation:

Price, E.W., T.H. Flemming, and L.A. Wainger. 2021. Cost Analysis of Stormwater and Agricultural Practices for Addressing Nitrogen and Phosphorus in Maryland. Prepared for Maryland Department of the Environment. UMCES Technical Report #TS-772-21

Acknowledgments:

The authors would like to acknowledge those individuals whose expert judgement and advice was critical to the completion of this analysis. Thanks to Greg Busch, Brian Cooper, and Jeff White of Maryland Department of the Environment, Jason Keppler and Alisha Mulkey of Maryland Department of Agriculture, Jerry Maldonado of Prince George's County Department of the Environment, and Olivia Devereux of Devereux Consulting for providing data, support, and insight. Additional thanks to Karl Berger of the Metropolitan Washington Council of Governments, Christine Buckley of the Harford County Department of Public Works, Ryan Cole of the Maryland State Highway Administration Office of Environmental Design, Donald Dorsey of Frederick County Office of Sustainability and Environmental Resources, Gale Engles of Carroll County Department of Land and Resource Management, Norm Goulet of the Northern Virginia Regional Commission, Kimberly Grove of Baltimore City Department of Public Works, Mark Richmond of Howard County Department of Public Works, Amy Stevens of Montgomery County Department of Environmental Protection, and Neil Weinstein of the Low Impact Development Center for their guidance during this analysis.

Revision History:

Changes to the November 2019 version (UMCES Technical Report # TS-730-19)

Section One: The IAE to CAST conversion factor for storm drain vacuuming and catch basin cleaning was corrected. This change affected the O&M and annualized costs for these practices. All tables and figures containing these practices were updated.

Changes to the March 2021 version (UMCES Technical Report # TS-772-21)

Section Two: Cost calculations for Grass Buffer – Narrow with Exclusion Fencing and Grass Buffer – Streamside with Exclusion Fencing have been modified to correct unit conversions. All tables and figures containing these practices were updated.

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Abstract

This report provides updated cost estimates for nonpoint source nutrient management practices (stormwater and agricultural) using data collected from Maryland state and local governments and federal agencies. Costs were evaluated for a subset of the practices defined by the Chesapeake Bay Partnership in the Chesapeake Assessment Scenario Tool (CAST). For urban stormwater practices, costs were also estimated for practices defined in Maryland's Municipal Separate Storm Sewer System (MS4) permit program. CAST cost information or assumptions were maintained, if new data were not available for those components of the cost calculation.

Costs were estimated with data available for Maryland and may not be directly transferable to other areas. For stormwater, median implementation costs were calculated from project data provided by counties that are regulated under the MS4 program (hereafter MS4 counties), which are relatively urbanized counties. The number of projects that were evaluated per practice varied from one to more than 70. Costs based on one or few projects may not provide robust estimates of typical costs due to variability of project costs. Data for agricultural practices were derived from two sources, 1) projects funded by the Maryland Agricultural Cost Share (MACS) program and 2) cost share reimbursement rates for Maryland from the 2017 USDA Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP).

Costs per pound reduction were considerably higher for stormwater practices than for agricultural BMPs. For stormwater practices, the median costs were $1,558/lb N and $9,639/lb P. For agricultural practices, median costs were $16/lb N and $489/lb P. Only practices with three or more projects were used to calculate medians.

In general, annualized costs per unit of stormwater practice were comparable to or higher (4%-4000%) than those in CAST. However, three practices had lower costs than CAST: stream restoration, filtering practices, and mechanical street sweeping. The main factors driving higher costs were higher average implementation costs and higher estimated operations and maintenance (O&M) costs. For many urban practices, annual O&M estimates were based on a percent of implementation or construction costs. The updated multipliers used here were 8.2% to 13.4%, compared with 2.5% to 6% in CAST. Another factor contributing to higher costs was that updated lifespan estimates were shorter for some practices (e.g., 20 years for infiltration practices instead of the 50 years used in CAST).

For agricultural practices, our analysis estimated that about 75% of the practices evaluated had higher estimated annualized cost per unit than CAST estimates, while 25% of practices had lower costs. Higher implementation, O&M costs and different lifespans (usually higher for MACS practices and lower for EQIP practices) were responsible for these cost differences. Agricultural land rental rates (opportunity costs) were also updated but generally had a modest effect on costs.

Section 1. Stormwater BMPs

Introduction

This report section describes methods used to create an updated set of cost estimates for a subset of the urban stormwater management practices that are available in the Chesapeake Assessment Scenario Tool (CAST) databases and in Maryland's Municipal Separate Storm Sewer System (MS4) program. We used practice implementation costs being collected by Maryland MS4 counties to inform our analysis. This section includes information about data sources used, significant assumptions, and methods used to estimate unit implementation costs, operations and maintenance (O&M) costs, opportunity costs, and annual costs.

This report accompanies two Excel workbooks (CAST and MS4 practice classifications) that provide median annual implementation costs per unit of practice and cost-efficiency in terms of cost per edge-of-tide pound of nitrogen and phosphorus removed, using efficiencies from CAST (as of September 2018). Each workbook includes a summary of annual costs and cost-efficiencies and worksheets of project costs and other detailed information on data inputs and calculations. The per practice costs and cost-efficiencies on the summary sheet will update if any of the input data on that sheet are changed are changed, thereby allowing users to see the effects of alternative assumptions.

Stormwater classification and data sources

Two classification systems were used to report costs for stormwater: CAST management practices and Maryland Department of the Environment (MDE) management practices used in MS4 permit reporting. Project-level data were obtained from MDE, and included BMP implementation costs from the Financial Assurance Plans that MS4 jurisdictions are required to submit every year, a spreadsheet from Maryland Department of Natural Resources (DNR) of projects funded by the Chesapeake and Coastal Bays Trust Fund, as well as access to the Phase I MS4 reports for the MS4 counties and the State Highway Administration (SHA). The MS4 reports themselves generally had a similar format from county to county, but the inclusion and format of cost information for specific projects varied across counties. We also had access to the geodatabases associated with each county's MS4 report. Most of these GIS files contain a table with cost information similar to what is included in the Financial Assurance Plans and annual MS4 reports.

Data sources included databases used to track Municipal Separate Storm Sewer System (MS4) implementation in Maryland counties and information from county and state officials. We selected the data source thought to contain the best quality data for each county, based on input from Brian Cooper of MDE. Table 1 shows which source or sources were included in the analysis. In some cases, where multiple sources were recommended, we opted to use only one source after examining the data. We did not include any data from the DNR Trust Fund spreadsheet in this version of the cost analysis because funding from the Trust Fund covers various (often isolated) phases of each project, and may or may not be comparable to the full implementation cost data from MDE.

Table 1. Stormwater data sources selected among overlapping databases provided by MDE per county

Jurisdiction	MDE-recommended source(s) and comments	Selected data source and rationale [a]
Anne Arundel	MS4 GDB	GDB
Baltimore City	FAP	FAP
Baltimore	FAP	FAP
Carroll	FAP	FAP
Charles	FAP better for older data. MS4 GDB better for newer data.	GDB – unusually low costs; use FAP only
Frederick	FAP	FAP
Harford	FAP and Annual Report Appendix C6	FAP and Appendix C6
Howard	Both the FAP and MS4 GDB contain cost data. Some data in the GDB is more complete than the FAP and vice versa.	Cost data in both sources contain duplicates; cost data appear too low in GDB; use FAP only
Montgomery	FAP	FAP
Prince George's	FAP	FAP
MDOT SHA	MS4 GDB from FY17 has data formatting issue. FY17 report would be more usable. FY18 report has updated costs data.	FY17 report [b]

[a] FAP = Financial Assurance Plan, GDB = MS4 Geodatabase

[b] As of February 2019, the FY18 report was not available on the Watershed Protection and Restoration Program - Financial Assurance Plans webpage (https://mde.state.md.us/programs/Water/StormwaterManagementProgram/Pages/WPRPFinancialAssurancePlans.aspx).

Compiling and refining the data

Data from selected data sources (Table 1) were screened and compiled into a master list in Microsoft Access using several steps. The data sources all contained fields for BMP type; impervious acres treated; implementation cost, status, and year; and the project's jurisdiction. For an individual record to be included in the dataset, each of these fields needed to contain relevant information. We excluded records with no or multiple BMP codes, records where the impervious area treated was blank or zero, records where the implementation cost field was blank or $0, and records with a status other than complete. The resulting master list had 494 records. A review of the data revealed that in some cases, two or more records had identical costs. These records were examined more closely and a set of rules was established to determine whether or not a record should remain in the master list.

1. Multiple records with the same cost, but different jurisdictions remained in the master list.
2. Multiple records with identical information (i.e., same jurisdiction, BMP type, cost, and acreage) were included one time and additional records were excluded (e.g., there were 77 Howard County rain gardens that treated 0.15 impervious acres and cost $5,202.34. One of these records was retained, and 76 were excluded).
3. Multiple records with the same jurisdiction, BMP type, cost and year, but different acreages were assumed to represent the cost to implement the sum of the acreages. A new record that included the cost and the sum of the acreage was created. Other records were excluded.
4. Multiple records with the same jurisdiction and cost, but different BMP types and acreages were excluded because the costs could not be apportioned to the practices.

After duplicate projects were removed following these rules, 353 projects remained for further analysis.

Adjusting the cost data to 2017 dollars

The resulting stormwater BMP dataset contained projects implemented in every year from 2007 to 2017. To summarize costs by BMP type, all costs were adjusted to 2017 dollars using the Construction Cost Index (CCI). CCI is a proprietary index to which we did not have access, but annual CCI values from 2007-2016 were obtained from CAST *[1]*.[1] We estimated a value for 2017 by taking the average of the year-to-year change in the index value from 2013-2014, 2014-2015, and 2015-2016 (see Table 2). This average change was added to the 2016 index value to estimate an index value for 2017. All values were then normalized to 2017 by dividing the 2017 value by each year's index value. Additionally, the project data from the SHA MS4 report did not specify the implementation year of the projects, so we made a conservative assumption that all projects were implemented in 2017.

Table 2. Cost adjustment factors for converting all costs to 2017$

Year	CCI Index Value	Year-to-year change	Factor
2005	7446		1.4238
2006	7751	305	1.3678
2007	7966	215	1.3309
2008	8310	344	1.2758
2009	8570	260	1.2371
2010	8802	232	1.2045
2011	9070	268	1.1689
2012	9308	238	1.1390
2013	9547	239	1.1105
2014	9806	**259**	1.0811
2015	10035	**229**	1.0565
2016	10338	**303**	1.0255
2017	*10602*	*264*	1.0000

Source of data prior to 2017: CAST *[1]*. The three values in **bold** were used to estimate an average annual increase from 2014-2016 (in *italics*), which was added to the 2016 index value to fill in the missing 2017 index value (also in italics). The factor, used to adjust monetary values to 2017 values, was calculated by dividing the 2017 index value by the index value for each year.

Cross-walking MDE BMP codes and CAST BMP types

MDE and CAST have different ways of grouping and defining some BMPs. We cross-walked MDE BMP codes and CAST BMP names using tables from MDE *[2]* and CAST *[3]*. In cases where there was no match, Jeff White identified the appropriate CAST BMP for the MDE BMP code (Table 3).

[1] Italicized numbers in brackets refer to references at the end of the report section.

Table 3. Crosswalk between MDE BMP codes and CAST BMP names

MDE BMP Code	MDE BMP Name	CAST BMP Name
MRNG	Rain Gardens	Bioretention/raingardens - A/B soils, underdrain
FBIO	Bioretention	Bioretention/raingardens - C/D soils, underdrain
MMBR	Micro-bioretention	Bioretention/raingardens - C/D soils, underdrain
MSWB	Bio-Swale	Bioswale
FORG	Organic Filter (Peat Filter)	Filtering Practices
FSND	Sand Filter	
FUND	Underground Filter	
FPU	Planting Trees or Forestation or Pervious Urban	Forest Planting
IMPP	Impervious Surface Elimination (to pervious)	Impervious Surface Reduction
IBAS	Infiltration Basin	Infiltration Practices w/ Sand, Veg. - A/B soils, no underdrain
ITRN	Infiltration Trench	
MSS	Mechanical Street Sweeping	Mechanical Broom Technology - 1 pass/2 weeks
VSS	Regenerative/Vacuum Street Sweeping	Advanced Sweeping Technology - 1 pass/2 weeks
APRP	Permeable Pavements	Permeable Pavement w/o Sand, Veg. - C/D soils, underdrain
SEPC	Septic Connection to WWTP	Septic Connection
SEPD	Septic Denitrification	Septic Denitrification-Conventional
SEPP	Septic Pumping	Septic Pumping
CBC	Catch Basin Cleaning	Storm Drain Cleaning
SDV	Storm Drain Vacuuming	
OUT	Outfall stabilization	Urban Stream Restoration
SPSC	Regenerative Step Pool Conveyance	
STRE	Stream Restoration	
NSCA	Sheetflow to Conservation Areas	Vegetated Open Channels - A/B soils, no underdrain
MSWG	Grass Swale	
ODSW	Dry Swale	
PWED	Extended Detention Structure, Wet	Wet Ponds and Wetlands
PWET	Retention Pond (Wet Pond)	
PMPS	Multiple Pond System	
MSGW	Submerged Gravel Wetlands	
PMED	Micropool Extended Detention Pond	
WSHW	Shallow Marsh	
WEDW	ED - Wetland	
WPWS	Wet Pond - Wetland	

From MDE-CAST Crosswalk tab in cost analysis spreadsheets.

MDE and CAST units

In Maryland, regulated counties have constructed many stormwater management practices to meet their impervious surface reduction targets as part of their MS4 permit. As a result, practices are generally measured by MDE as impervious surface treated or Impervious Area Equivalents (IAE), which differs from the units used in CAST to track stormwater BMPs (Table 4). Project units were converted from IAE to the relevant CAST units where necessary (Table 5). Additionally, in CAST, “acres treated” refers to total acres (i.e., pervious and impervious), so for practices with a unit of “acres treated,” IAEs were converted to total acres treated by dividing by the percent of urban land that is impervious for the state of Maryland (i.e., 35.0%).[2] This conversion was not necessary for practices with other CAST units.

Table 4. Stormwater BMP units used in the CAST model

CAST BMP Name	Unit
Forest Planting	acres
Impervious Surface Reduction	acres
Advanced Sweeping Technology - 1 pass/2 weeks	acres or miles
Mechanical Broom Technology - 1 pass/2 weeks	acres or miles
Bioretention/raingardens - A/B soils, underdrain	acres treated
Bioretention/raingardens - C/D soils, underdrain	acres treated
Bioswale	acres treated
Filtering Practices	acres treated
Infiltration Practices w/ Sand, Veg. - A/B soils, no underdrain	acres treated
Permeable Pavement w/o Sand, Veg. - C/D soils, underdrain	acres treated
Vegetated Open Channels - A/B soils, no underdrain	acres treated
Wet Ponds and Wetlands	acres treated
Storm Drain Cleaning	lbs TSS
Urban Stream Restoration	linear feet
Septic Connection	# of systems
Septic Denitrification-Conventional	# of systems
Septic Pumping	# of systems

From Summary tab in CAST cost analysis spreadsheet

[2] Percent impervious estimate was derived from urban impervious area data developed by MDE. Impervious urban area includes roads, non-road impervious, and tree canopy over impervious. Pervious urban areas are turf or tree canopy over turf (Jeff White, personal communication).

Table 5. MDE to CAST BMP conversion factors

MDE BMP Code	MDE BMP Name	IAE to CAST Conversion Factor	Conversion Factor Units
FPU	Planting Trees or Forestation on Pervious Urban	0.38	IAE/acre
IMPP	Impervious Surface Elimination (to pervious)	1.00	IAE/acre
VSS	Regenerative/Vacuum Street Sweeping	0.13	IAE/mile swept
MSS	Mechanical Street Sweeping	0.07	IAE/mile swept
APRP	Permeable Pavements	1.00	IAE/acre treated
FBIO	Bioretention	1.00	IAE/acre treated
FORG	Organic Filter (Peat Filter)	1.00	IAE/acre treated
FSND	Sand Filter	1.00	IAE/acre treated
FUND	Underground Filter	1.00	IAE/acre treated
IBAS	Infiltration Basin	1.00	IAE/acre treated
ITRN	Infiltration Trench	1.00	IAE/acre treated
MMBR	Micro-Bioretention	1.00	IAE/acre treated
MRNG	Rain Gardens	1.00	IAE/acre treated
MSGW	Submerged Gravel Wetlands	1.00	IAE/acre treated
MSWB	Bio-Swale	1.00	IAE/acre treated
MSWG	Grass Swale	1.00	IAE/acre treated
NSCA	Sheetflow to Conservation Areas	1.00	IAE/acre treated
ODSW	Dry Swale	1.00	IAE/acre treated
PMED	Micropool Extended Detention Pond	1.00	IAE/acre treated
PMPS	Multiple Pond System	1.00	IAE/acre treated
PWED	Extended Detention Structure, Wet	1.00	IAE/acre treated
PWET	Retention Pond (Wet Pond)	1.00	IAE/acre treated
WEDW	ED - Wetland	1.00	IAE/acre treated
WPWS	Wet Pond - Wetland	1.00	IAE/acre treated
WSHW	Shallow Marsh	1.00	IAE/acre treated
SDV	Storm Drain Vacuuming	0.001	IAE/lb TSS
CBC	Catch Basin Cleaning	0.001	IAE/lb TSS
STRE	Stream Restoration	0.01	IAE/lf
SPSC	Regenerative Step Pool Conveyance	0.01	IAE/lf
OUT	Outfall Stabilization	0.01	IAE/lf
SEPP	Septic Pumping	0.03	IAE/pumpout
SEPC	Septic Connection to WWTP	0.39	IAE/connection
SEPD	Septic Denitrification	0.26	IAE/septic denitrification

All MDE BMPs use IAE as the unit. Note that IAEs are divided by the conversion factor to generate CAST units. From Conversion Factors tab in cost analysis spreadsheets

BMP lifespan

BMP lifespan was defined as the time from construction to a major overhaul or complete replacement. Defining the lifespan of each BMP type was necessary to annualize BMP costs. Potential sources of BMP lifespan information were identified *[1, 4, 5, 6, 7, 8, 9]* and supplemented by MS4 county stormwater administrators' best professional judgement on BMP lifespan. A lifespan estimate that represented the midrange of all estimates gathered was chosen for each practice (Table 6). For most practices, the midrange estimate came from MDE *[4]*. Exceptions where other sources represented the midrange include Catch Basin Cleaning, Storm Drain Vacuuming, and Septic Pumping *[1, 7, 8, 9]*, street sweeping practices *[6]*, and the practices that fall into the "Wet Ponds and Wetlands" category *[10]*.

Table 6. SW BMP Lifespan estimates used in analysis

CAST BMP Name	MDE BMP Codes	Lifespan (years)
Wet Ponds and Wetlands	MSGW, PMED, PMPS, PWED, PWET, WEDW, WPWS, WSHW	30
Urban Stream Restoration	OUT, SPSC, STRE	20
Forest Planting	FPU	20
Filtering Practices	FORG, FSND, FUND	20
Bioretention/raingardens - C/D soils, underdrain	FBIO, MMBR	20
Infiltration Practices w/ Sand, Veg. - A/B soils, no underdrain	IBAS, ITRN	20
Bioretention/raingardens - A/B soils, underdrain	MRNG	20
Vegetated Open Channels - A/B soils, no underdrain	MSWG, NSCA, ODSW	20
Septic Denitrification-Conventional	SEPD	20
Septic Connection	SEPC	20
Permeable Pavement w/o Sand, Veg. - C/D soils, underdrain	APRP	20
Impervious Surface Reduction	IMPP	20
Bioswale	MSWB	20
Mechanical Broom Technology - 1 pass/2 weeks	MSS	10
Advanced Sweeping Technology - 1 pass/2 weeks	VSS	10
Septic Pumping	SEPP	5
Storm Drain Cleaning	CBC, SDV	1

Included in Summary tab in cost analysis spreadsheets.

Summarizing data by MDE BMP code and CAST BMP type

The cost analysis is summarized in two spreadsheets: SW BMP Costs – MDE Codes (organized by MDE BMP code) and SW BMP Costs – CAST BMPs (organized by CAST BMP names). In both versions, costs are presented using the relevant units for each BMP (e.g., IAE in the MDE version and a variety of units in the CAST version). For each BMP type, minimum, maximum, and median values for implementation costs per unit are shown. We present median rather than average value because unit costs included large outlier costs. Median costs reveal the "central tendency" of the project costs, even with outliers present. Methods for estimating annual O&M costs, land costs, and annualized costs are described in the sections that follow. Additionally, in the CAST version, the cost efficiency of each practice using estimates of pounds of N and P reduced per unit of practice is included (methods described below).

Estimating O&M costs

Cost data in the stormwater BMP dataset included aggregated implementation costs only, and omitted costs associated with O&M and other sources of costs. We developed a strategy to estimate O&M costs for each BMP using information from CAST *[1, 7, 8, 9]* and the MS4 counties. We requested records of O&M costs for stormwater BMPs from county MS4 administrators. Several counties replied with varying degrees of specificity, but Prince George's (PG) County provided the most detailed and comprehensive approach for estimating O&M costs for many practices *[10]*. For practices not included in PG County's approach, we followed CAST's methods of estimating O&M costs.

O&M costs as a percent of construction costs

O&M costs for many practices in the CAST and PG County approaches were estimated as a percent of construction or installation costs. The PG County approach assumes that O&M varies by practice in frequency and intensity, and the costs associated with each level of intensity are estimated as a percent of installation costs (Table 7). We created an annual multiplier for O&M by combining maintenance intensity and frequency per practice (Table 8). For the BMPs included in PG County's strategy, annual O&M costs ranged from 8.2% of installation costs (stream restoration) to 13.4% (infiltration practices). In both the MDE and CAST versions of the cost analysis, we estimated O&M costs by applying the PG County annualized O&M multipliers to the median per unit implementation costs of the relevant practices.

O&M for other practices

For BMPs not included in PG County's approach, we used O&M estimates from the CAST cost spreadsheets *[1, 7, 8, 9]*. Costs from the CAST spreadsheets were updated to 2017 dollars using the methods described in a previous section. When we estimated O&M costs for the MDE BMPs, we also converted the CAST units (i.e., $/lf/year, $/lb TSS/year, and $/system/year) to IAE according to the conversion table from MDE (see Table 5).

Table 7. O&M intensity levels and estimated costs as a percent of installation costs, as derived from Prince George's County approach

Level of Intensity	**Types of activities**	**Percent of installation costs**
Routine	Aesthetics maintenance (e.g., seasonal planting, trash removal, etc.)	5%
Level 1	Moderate repair (e.g., replacement of shrubs or trees, structural unclogging, underground storage filter cartridge replacement)	10-15% [a]
Level 2	Significant repair (e.g., regrading, removal of accumulated sediments, repair of erosion issues)	35-50% [b]

[a] 12.5% (the mid-point of 10-15%) was the multiplier for Level 1 repairs.

[b] 42.5% (the mid-point of 35-50%) was the multiplier for Level 2 repairs.

Table 8. O&M multipliers derived from the Prince George's County approach

BMPs	Frequency (years)			Annual multiplier [a]			O&M Multiplier
	Routine [b]	Level 1 [c]	Level 2 [d]	Routine	Level 1	Level 2	
Micro-scale (bioretention, rain gardens, bioswale, grass swale, dry swale)	1	4	12.5	5.0%	3.13%	3.4%	11.5%
Filtering practices	1	4	12.5	5.0%	3.13%	3.4%	11.5%
Infiltration practices (plus permeable pavements)	1	3	10	5.0%	4.17%	4.25%	13.4%
Ponds	1	4	12.5	5.0%	3.13%	3.4%	11.5%
Wetlands [e]	3	10	NA	1.67%	1.25%	NA	2.9%
Stream restoration	3	4	12.5	1.67%	3.13%	3.4%	8.2%

[a] Annual multipliers were calculated by dividing the appropriate percent of installation costs (Table 7) by the frequency of the maintenance. The overall O&M multiplier is the sum of the annual multipliers for each practice to evaluate the total O&M over the project lifespan.
[b] Per PG County, routine maintenance could be as frequent as semi-annually or quarterly for some practices. We limited the frequency to no more than once per year.
[c] For several practices, frequency of Level 1 maintenance was estimated at 3-5 years. We used 4 years (the mid-point of 3-5) as the frequency for these BMPs.
[d] For several practices, frequency of Level 2 maintenance was estimated at 10-15 years. We used 12.5 years (the mid-point of 10-15) as the frequency for these BMPs. For wetlands, it is assumed that once plantings are mature, further maintenance will not be required.
[e] In this context, "wetlands" refers to non-structural wetland BMPs like wetland enhancement. The wetland BMPs in this analysis are expected to have O&M costs similar to pond BMPs (Jeff White, personal communication).

Exceptions

Several BMPs required different procedures or assumptions.

- Forest planting – O&M associated with planting trees is generally built into the cost of installation *[10]*, so additional O&M costs are assumed to be $0. Built-in O&M includes watering, tree protection (i.e., from deer), and tree replacement (5% is generally assumed).
- Storm Drain Cleaning (Catch Basin Cleaning and Storm Drain Vacuuming in MDE version) – O&M involves both maintenance of the unit itself and annual cleaning/vacuuming costs. For this BMP, a 5% multiplier was used to estimate unit maintenance costs, and costs per lb TSS removed were added *[1]*.
- Septic connection to public sewer – O&M costs are assumed to be $0.
- Septic pumping – CAST provided O&M costs based on different pumping frequencies *[8]*. We assumed pumping occurs every five years.
- Permeable pavement – We obtained an estimate from King and Hagan, and updated the costs from 2011$ to 2017$ *[6]*.
- Impervious surface reduction – O&M would depend on the practice installed following impervious surface removal and would then be equivalent to the O&M for the new BMP. We used a $0.01 placeholder O&M cost for impervious surface reduction. Note that this approach is different from CAST which assumed 5% of construction costs, minus the impervious surface maintenance that would have been done without the BMP.

Table 9 and Table 10 show the O&M multipliers and estimated costs for all CAST and MDE BMPs.

Table 9. O&M multipliers (where applicable) and estimated O&M cost per unit per year in the CAST version of Stormwater BMP cost analysis

CAST BMP Name	Unit	O&M Multiplier	O&M Costs/ unit/yr
Wet Ponds and Wetlands	acres treated	11.5%	$1,937
Urban Stream Restoration	linear feet	8.2%	$47
Forest Planting	acres	NA	$0
Filtering Practices	acres treated	11.5%	$697
Bioretention/raingardens - C/D soils, underdrain	acres treated	11.5%	$7,598
Infiltration Practices w/ Sand, Veg. - A/B soils, no underdrain	acres treated	11.5%	$2,471
Bioretention/raingardens - A/B soils, underdrain	acres treated	11.5%	$5,313
Storm Drain Cleaning	lbs TSS	5.0%	$1
Vegetated Open Channels - A/B soils, no underdrain	acres treated	11.5%	$9,000
Mechanical Broom Technology - 1 pass/2 weeks	acres or miles	NA	$1,481
Septic Denitrification-Conventional	# of systems	NA	$385
Septic Connection	# of systems	NA	$0
Advanced Sweeping Technology - 1 pass/2 weeks	acres or miles	NA	$740
Permeable Pavement w/o Sand, Veg. - C/D soils, underdrain	acres treated	13.4%	$16,351
Impervious Surface Reduction	acres	NA	$0
Bioswale	acres treated	11.5%	$2,159
Septic Pumping	# of systems	NA	$108

From O&M Costs tab in CAST cost analysis spreadsheet

Table 10. O&M multipliers (where applicable) and estimated O&M cost per IAE per year in the MDE BMP code version of Stormwater BMP cost analysis

MDE BMP Code	MDE BMP Name	O&M Multiplier	O&M costs/ IAE/yr
FPU	Planting Trees or Forestation or Pervious Urban	NA	$0
STRE	Stream Restoration	8.2%	$4,477
PWET	Retention Pond (Wet Pond)	11.5%	$5,532
FSND	Sand Filter	11.5%	$1,930
SPSC	Regenerative Step Pool Conveyance	8.2%	$5,518
FBIO	Bioretention	11.5%	$21,715
PWED	Extended Detention Structure, Wet	11.5%	$2,964
MRNG	Rain Gardens	11.5%	$15,186
IBAS	Infiltration Basin	13.4%	$8,228
CBC	Catch Basin Cleaning	5.0%	$217
MSWG	Grass Swale	11.5%	$25,720
WEDW	ED - Wetland	11.5%	$2,034
WPWS	Wet Pond - Wetland	11.5%	$1,507
MSS	Mechanical Street Sweeping	NA	$21,154
SEPD	Septic Denitrification	NA	$1,482
MMBR	Micro-bioretention	11.5%	$32,002
SEPC	Septic Connection to WWTP	NA	$0
FUND	Underground Filter	11.5%	$11,621
WSHW	Shallow Marsh	11.5%	$956
SDV	Storm Drain Vacuuming	5.0%	$289
ITRN	Infiltration Trench	13.4%	$14,571
MSGW	Submerged Gravel Wetlands	11.5%	$4,191
APRP	Permeable Pavements	13.4%	$46,730
PMED	Micropool Extended Detention Pond	11.5%	$7,806
VSS	Regenerative/Vacuum Street Sweeping	NA	$5,695
FORG	Organic Filter (Peat Filter)	11.5%	$22,612
IMPP	Impervious Surface Elimination (to pervious)	NA	$0.01
MSWB	Bio-Swale	11.5%	$6,171
ODSW	Dry Swale	11.5%	$20,960
OUT	Outfall stabilization	8.2%	$15,251
PMPS	Multiple Pond System	11.5%	$16,775
SEPP	Septic Pumping	NA	$3,613
NSCA	Sheetflow to Conservation Areas	11.5%	$166,920

From O&M Costs tab in MDE BMP cost analysis spreadsheet

Estimating land (opportunity) costs

Land costs are referred to as opportunity costs because land used for stormwater BMPs is land that will not be available to be developed for other purposes. Thus, the lost opportunity to develop the land is another cost of installing a stormwater practice. We did not update the opportunity costs of urban land and used the land values from CAST of $110,000 per developable acre for Maryland *[1]*. The value of land can vary greatly within and among counties in Maryland, but the CAST value is the best estimate currently available. Following methods from King and Hagan that were also used in CAST *[6]*, we assumed that 50% of BMPs are constructed on land that would be developable and 50% are constructed on land that is not developable (e.g., because it is adjacent to streams), so the estimated opportunity cost of land associated with construction of stormwater BMPs is $55,000 per acre. This value was applied only to the land area that a BMP occupies, which is represented as the percentage of treated area (Table 11) for BMPs that require land (Table 12). For forest planting, to be consistent with other calculated costs, we divided the opportunity cost per acre by 0.38 *[11]* to convert cost units to dollars per IAE.

Table 11. Estimated land area occupied by listed stormwater BMP

CAST BMP Name	Corresponding MDE BMP Codes	Percent of land area
Wet Ponds and Wetlands	MSGW, PMED, PMPS, PWED, PWET, WEDW, WPWS, WSHW	4%
Vegetated Open Channels	MSWG, NSCA, ODSW	
Bioswale	MSWB	
Bioretention/raingardens	FBIO, MMBR, MRNG	6%
Filtering Practices	FORG, FSND, FUND	10%
Infiltration Practices	IBAS, ITRN	
Impervious Surface Reduction	IMPP	100%

Derived from King and Hagan (2011).

Table 12. Estimated opportunity costs of land for stormwater BMPs

CAST BMP Name	MDE BMP Codes	Land costs/IAE
Wet Ponds and Wetlands	MSGW,PMED, PMPS, PWED, PWET, WEDW, WPWS, WSHW	$2,200
Urban Stream Restoration	OUT, SPSC, STRE	NA
Forest Planting	FPU	$144,737
Filtering Practices	FORG, FSND, FUND	$5,500
Bioretention/raingardens - C/D soils, underdrain	FBIO, MMBR	$3,300
Infiltration Practices w/ Sand, Veg. - A/B soils, no underdrain	IBAS, ITRN	$5,500
Bioretention/raingardens - A/B soils, underdrain	MRNG	$3,300
Storm Drain Cleaning	CBC, SDV	NA
Vegetated Open Channels - A/B soils, no underdrain	MSWG, NSCA, ODSW	$2,200
Mechanical Broom Technology - 1 pass/2 weeks	MSS	NA
Septic Denitrification-Conventional	SEPD	NA
Septic Connection	SEPC	NA
Advanced Sweeping Technology - 1 pass/2 weeks	VSS	NA
Permeable Pavement w/o Sand, Veg. - C/D soils, underdrain	APRP	NA
Impervious Surface Reduction	IMPP	$55,000
Bioswale	MSWB	$2,200
Septic Pumping	SEPP	NA

From Land Costs tab in cost analysis spreadsheets

Annual and annualizing costs

Two methods to estimate annual costs for each stormwater BMP were used. Results for each practice are shown in the summary tables (Table 15 and Table 16) below.

Equations (1) and (2) were used to estimate "simple" annual costs without and with land costs. In these equations, no annualization (i.e., interest) rate is used.

Simple annual costs without land costs:

$$AC = \frac{implementation\ costs}{lifespan} + O\&M\ costs \tag{1}$$

Simple annual costs with land costs:

$$AC = \frac{implementation\ costs + land\ costs}{lifespan} + O\&M\ costs \tag{2}$$

For annualized costs, we used equations (3) and (4). In these calculations, implementation costs were spread over the lifespan of the project after assuming a 5% annualization rate. Because O&M costs are paid on an annual basis, they were added after annualizing implementation costs. The annualization of the median implementation costs in these equations is equivalent to using the "PMT" function in Excel. This function calculates periodic payments for a loan based on constant payments and a constant interest rate.

Annualization without land costs:

$$AC = \left[implementation\ costs \times \left(\frac{r}{(1+r)^{lifespan} - 1} + r\right)\right] + O\&M\ costs \tag{3}$$

Annualization with land costs:

$$AC = \left[implementation\ costs \times \left(\frac{r}{(1+r)^{lifespan} - 1} + r\right)\right] + (land\ costs \times r) + O\&M\ costs \tag{4}$$

Calculating cost efficiencies

For the CAST BMPs, we calculated the cost-efficiency of each BMP (i.e., cost per pound of nutrient reduction) using estimates of the pounds of nitrogen and phosphorus reduced at the edge-of-tide (EOT) per unit from CAST (Table 13) *[12]*. This analysis used the values for the state of Maryland generated by the watershed model, rather than the values for the other watershed states or the finer county-scale averages. Note that the phosphorus reduction value for Impervious Surface Reduction is negative because impervious surface is sometimes replaced by turfgrass, which may have fertilizer applied *[13]*.

Table 13. Pounds of nitrogen and phosphorus reduction per unit of BMP

CAST BMP Name	Unit	Lbs N Reduced (EOT)/Unit-Yr	Lbs P Reduced (EOT)/Unit-Yr
Wet Ponds and Wetlands	acres treated	1.6649	0.3186
Urban Stream Restoration	linear feet	0.0592	0.0461
Forest Planting	acres	6.1453	0.7732
Filtering Practices	acres treated	3.3297	0.4248
Bioretention/raingardens - C/D soils, underdrain	acres treated	2.0811	0.3186
Infiltration Practices w/ Sand, Veg. - A/B soils, no underdrain	acres treated	7.0756	0.6018
Bioretention/raingardens - A/B soils, underdrain	acres treated	5.8270	0.5311
Storm Drain Cleaning	lbs TSS	0.0021	0.0004
Vegetated Open Channels - A/B soils, no underdrain	acres treated	3.7460	0.3186
Mechanical Broom Technology - 1 pass/2 wks	acres or miles	0.0000	0.0000
Septic Denitrification-Conventional	# of systems	4.1002	0.0000
Septic Connection	# of systems	8.2004	0.0000
Advanced Sweeping Technology - 1 pass/2 wks	acres or miles	0.2347	0.0307
Permeable Pavement w/o Sand, Veg. - C/D soils, underdrain	acres treated	0.8324	0.1416
Impervious Surface Reduction	acres	4.6500	-0.1596
Bioswale	acres treated	5.8270	0.5311
Septic Pumping	# of systems	0.4100	0.0000

See Summary tab in accompanying cost analysis spreadsheets

Final summary tables

We compared annualized costs from CAST with our analysis results (Table 14). In general, the costs estimated in this analysis were higher than those in CAST. Costs for urban stream restoration, filtering practices, and mechanical street sweeping were lower in this analysis than in CAST. Costs for other practices were 4% to 4,200% higher in this analysis than in CAST. The higher O&M costs estimated in this analysis are a major factor in the higher costs, while shorter project lifespans have a more modest effect.

The information described in the previous sections was all compiled and presented in two summary tables: one organized by MDE BMP codes (Table 15) and the other organized by CAST BMP names (Table 16).

Table 14. Average annualized costs from this analysis compared with average annualized costs from CAST

CAST BMP Name	**Unit**	**Annualized cost/unit (this analysis)**	**CAST annualized cost/unit**	**Percent change from CAST**
Wet Ponds and Wetlands	acres treated	$3,071	$330	831%
Urban Stream Restoration	linear feet	$92	$145	-36%
Forest Planting	acres	$3,715	$90	4,028%
Filtering Practices	acres treated	$1,279	$2,321	-45%
Bioretention/raingardens - C/D soils, underdrain	acres treated	$12,957	$1,058	1,125%
Infiltration Practices w/ Sand, Veg. - A/B soils, no underdrain	acres treated	$4,291	$1,092	293%
Bioretention/raingardens - A/B soils, underdrain	acres treated	$9,079	$1,058	758%
Storm Drain Cleaning	lbs TSS	$5	$0.62	651%
Vegetated Open Channels - A/B soils, no underdrain	acres treated	$15,318	$817	1,775%
Mechanical Broom Technology - 1 pass/2 weeks	acres or miles	$1,492	$1,646	-9%
Septic Denitrification-Conventional	# of systems	$1,237	$1,192	4%
Septic Connection	# of systems	$1,096	$527	108%
Advanced Sweeping Technology - 1 pass/2 weeks	acres or miles	$780	$732	7%
Permeable Pavement w/o Sand, Veg. - C/D soils, underdrain	acres treated	$26,142	$14,214	84%
Impervious Surface Reduction	acres	$68,202	$14,214	380%
Bioswale	acres treated	$3,704	$865	328%
Septic Pumping	# of systems	$138	$60	130%

Table 15. Summary of stormwater BMP cost analysis summarized by MDE BMP codes

MDE BMP Code	MDE BMP Name	Count	Lifespan (yrs)	Implementation Cost per IAE			Annual O&M Costs per IAE	Simple Annual Unit Costs		Annualized Unit Costs	
				Minimum	Maximum	Median		No land costs	With land costs	No land costs	With land costs
FPU	Planting Trees or Forestation or Pervious Urban	73	20	$6,853	$1,787,246	$31,649	$0	$1,582	$8.819	$2,540	$9,776
STRE	Stream Restoration	54	20	$12,072	$599,731	$54,602	$4,477	$7,208	$7,208	$8,859	$8,859
PWET	Retention Pond (Wet Pond)	50	30	$6,238	$210,682	$48,104	$5,532	$7,135	$7,209	$8,661	$8,771
FSND	Sand Filter	48	20	$1,717	$113,775	$16,779	$1,930	$2,769	$3,044	$3,276	$3,551
SPSC	Regenerative Step Pool Conveyance	24	20	$6,907	$1,770,662	$67,293	$5,518	$8,883	$8,883	$10,918	$10,918
FBIO	Bioretention	13	20	$8,575	$587,397	$188,823	$21,715	$31,156	$31,321	$36,866	$37,031
PWED	Extended Detention Structure, Wet	11	30	$340	$85,736	$25,774	$2,964	$3,823	$3,897	$4,641	$4,751
MRNG	Rain Gardens	9	20	$3,331	$348,738	$132,049	$15,186	$21,788	$21,953	$25,782	$25,947
IBAS	Infiltration Basin	8	20	$8,740	$197,270	$61,405	$8,228	$11,299	$11,574	$13,156	$13,431
CBC	Catch Basin Cleaning	5	1	$1,388	$7,328	$2,704	$217	$2,921	$2,921	$3,056	$3,056
MSWG	Grass Swale	5	20	$48,861	$919,232	$223,656	$25,720	$36,903	$37,013	$43,667	$43,777
WEDW	ED - Wetland	5	30	$45,268	$234,665	$70,135	$8,066	$10,403	$10,477	$12,628	$12,738
WPWS	Wet Pond - Wetland	5	30	$30,521	$61,740	$51,950	$5,974	$7,706	$7,779	$9,354	$9,464
MSS	Mechanical Street Sweeping	5	10	$644	$2,298	$1,225	$21,154	$21,276	$21,276	$21,312	$21,312
SEPD	Septic Denitrification	4	20	$14,579	$57,384	$40,836	$1,482	$3,524	$3,524	$4,759	$4,759
MMBR	Micro-bioretention	4	20	$101,395	$5,607,426	$278,276	$32,002	$45,915	$46,080	$54,331	$54,441
SEPC	Septic Connection to WWTP	3	20	$5,894	$138,608	$35,029	$0	$1,751	$1,751	$2,811	$2,811
FUND	Underground Filter	3	20	$78,093	$185,384	$101,052	$11,621	$16,674	$16,949	$19,730	$20,005
WSHW	Shallow Marsh	3	30	$15,218	$73,736	$32,953	$3,790	$4,888	$4,961	$5,933	$6,043
SDV	Storm Drain Vacuuming	3	1	$3,804	$5,281	$4,150	$289	$4,439	$4,439	$4,647	$4,647
ITRN	Infiltration Trench	2	20	$6,676	$210,798	$108,737	$14,571	$20,008	$20,283	$23,296	$23,571

MDE BMP Code	MDE BMP Name	Count	Lifespan (yrs)	Implementation Cost per IAE			Annual O&M Costs per IAE	Simple Annual Unit Costs		Annualized Unit Costs	
				Minimum	Maximum	Median		No land costs	With land costs	No land costs	With land costs
MSGW	Submerged Gravel Wetlands	2	30	$115,788	$173,261	$144,524	$16,620	$21,438	$21,511	$26,022	$26,132
APRP	Permeable Pavements	2	20	$272,878	$424,580	$348,729	$46,730	$64,166	$64,166	$74,713	$74,713
PMED	Micropool Extended Detention Pond	2	30	$33,329	$102,435	$67,882	$7,806	$10,069	$10,143	$12,222	$12,332
VSS	Regenerative/Vacuum Street Sweeping	2	10	$1,680	$3,016	$2,348	$5,695	$5,930	$5,930	$5,999	$5,999
FORG	Organic Filter (Peat Filter)	1	20	$196,626	$196,626	$196,626	$22,612	$32,443	$32,718	$38,390	$38,665
IMPP	Impervious Surface Elimination (to pervious)	1	20	$815,673	$815,673	$815,673	$0	$40,784	$43,534	$65,452	$68,202
MSWB	Bio-Swale	1	20	$53,660	$53,660	$53,660	$6,171	$8,854	$8,964	$10,477	$10,587
ODSW	Dry Swale	1	20	$182,260	$182,260	$182,260	$20,960	$30,073	$30,183	$35,585	$35,695
OUT	Outfall stabilization	1	20	$185,989	$185,989	$185,989	$15,251	$24,551	$24,551	$30,175	$30,175
PMPS	Multiple Pond System	1	30	$145,870	$145,870	$145,870	$16,775	$21,637	$21,711	$26,264	$26,374
SEPP	Septic Pumping	1	5	$4,236	$4,236	$4,236	$3,613	$4,461	$4,461	$4,592	$4,592
NSCA	Sheetflow to Conservation Areas	1	20	$1,451,476	$1,451,476	$1,451,476	$166,920	$239,494	$239,604	$283,390	$283,500

Practices shaded in gray had fewer than 3 records in the database. From MDE SW BMP Summary tab in MDE cost analysis spreadsheet.

Table 16. Summary of stormwater BMP cost analysis summarized by CAST BMP Name

CAST BMP Name	Unit	Count	Lifespan (years)	Implementation Cost per unit			Annual O&M Costs per unit	Simple Annual Unit Costs		Annualized Unit Costs		Cost efficiency	
				Minimum	Maximum	Median		No land costs	With land costs	No land costs	With land costs	$/lb of N (EOT) reduction	$/lb of P (EOT) reduction
Wet Ponds and Wetlands	acres treated	79	30	$119	$82,109	$16,843	$1,937	$2,498	$2,524	$3,033	$3,071	$1,845	$9,639
Urban Stream Restoration	linear feet	79	20	$69	$17,707	$568	$47	$75	$75	$92	$92	$1,559	$2,001
Forest Planting	acres	73	20	$2,604	$679,154	$12,027	$0	$601	$3,351	$965	$3,715	$605	$4,805
Filtering Practices	acres treated	52	20	$601	$68,799	$6,057	$697	$999	$1,096	$1,183	$1,279	$384	$3,010
Bioretention/raingardens - C/D soils, underdrain	acres treated	17	20	$3,000	$1,962,038	$66,069	$7,598	$10,901	$10,959	$12,900	$12,957	$6,226	$40,665
Infiltration Practices w/ Sand, Veg. - A/B soils, no underdrain	acres treated	10	20	$2,336	$73,758	$21,486	$2,471	$3,545	$3,641	$4,195	$4,291	$606	$7,130
Bioretention/raingardens - A/B soils, underdrain	acres treated	9	20	$1,166	$122,023	$46,204	$5,313	$7,624	$7,681	$9,021	$9,079	$1,558	$17,096
Storm Drain Cleaning	lbs TSS	8	1	$1	$7	$4	$1	$4	$4	$5	$5	$2,185	$11,350
Vegetated Open Channels - A/B soils, no underdrain	acres treated	7	20	$17,096	$507,871	$78,257	$9,000	$12,912	$12,951	$15,279	$15,318	$4,089	$48,073
Mechanical Broom Technology - 1 pass/2 weeks	acres or miles	5	10	$45	$161	$86	$1,481	$1,489	$1,489	$1,492	$1,492	NA	NA
Septic Denitrification-Conventional	# of systems	4	20	$3,791	$14,920	$10,617	$385	$916	$916	$1,237	$1,237	$302	NA
Septic Connection	# of systems	3	20	$2,299	$54,057	$13,661	$0	$683	$683	$1,096	$1,096	$134	NA
Advanced Sweeping Technology - 1 pass/2 weeks	acres or miles	2	10	$218	$392	$305	$740	$771	$771	$780	$780	$3,322	$25,404

CAST BMP Name	Unit	Count	Lifespan (years)	Implementation Cost per unit			Annual O&M Costs per unit	Simple Annual Unit Costs		Annualized Unit Costs		Cost efficiency	
				Minimum	Maximum	Median		No land costs	With land costs	No land costs	With land costs	$/lb of N (EOT) reduction	$/lb of P (EOT) reduction
Permeable Pavement w/o Sand, Veg. - C/D soils, underdrain	acres treated	2	20	$95,480	$148,560	$122,020	$16,351	$22,452	$22,452	$26,142	$26,142	$31,404	$184,579
Impervious Surface Reduction	acres	1	20	$815,673	$815,673	$815,673	$0	$40,784	$43,534	$65,452	$68,202	$14,667	-$427,383
Bioswale	acres treated	1	20	$18,776	$18,776	$18,776	$2,159	$3,098	$3,136	$3,666	$3,704	$636	$6,975
Septic Pumping	# of systems	1	5	$127	$127	$127	$108	$134	$134	$138	$138	$336	NA
											Average	**$1,772**	**$15,974**
											Median	**$1,558**	**$9,639**

Practices shaded in gray had fewer than 3 records in the database. From CAST SW BMP Summary tab in CAST cost analysis spreadsheet.
Average and median cost efficiencies include all practices with 3 or more records in the database.

Data Sources for Urban Stormwater Practices

1. Urban BMP Costs Details RTI revised.xlsx: CAST, Public Reports, Cost Profiles, BMP Cost Data Sources, Developed: Additional (http://cast.chesapeakebay.net/FileBrowser/GetFile?fileName=Urban%20BMP%20Costs%20Details%20RTI%20revised.xlsx). Last accessed February 26, 2019. CCI values were found in the Assumptions sheet.

2. New MDE SWM Codes.xlsx from Jeff White, MDE.

3. Commonly Used BMP Names.xlsx: CAST, Develop a Plan, Nomenclature (http://cast.chesapeakebay.net/FileBrowser/GetFile?fileName=Commonly%20Used%20BMP%20Names.xlsx). Last accessed February 26, 2019.

4. Maryland Department of the Environment. 2017. BMP Unit Cost Estimate Spreadsheet.

5. Claytor, R.A. and T.R. Schueler. 1996. Design of Stormwater Filtering Systems. Prepared for the Chesapeake Research Consortium, Inc.

6. King, D. and P. Hagan. 2011. Costs of stormwater management practices in Maryland counties. Prepared for Maryland Department of the Environment Science Services Administration. Reference Number UMCES CBL, 11-043.

6. Urban BMP Unit Costs.xlsx: CAST, Public Reports, Cost Profiles, BMP Cost Data Sources, Developed: Original (http://cast.chesapeakebay.net/FileBrowser/GetFile?fileName=Urban%20BMP%20Unit%20Costs.xlsx). Last accessed February 28, 2019.

8. Septic System Unit Costs.xlsx: CAST, Public Reports, Cost Profiles, BMP Cost Data Sources, Septic: Original (http://cast.chesapeakebay.net/FileBrowser/GetFile?fileName=Septic%20System%20Unit%20Costs.xlsx). Last accessed February 28, 2019.

9. Septic System Unit Costs Details RTI.xlsx: CAST, Public Reports, Cost Profiles, BMP Cost Data Sources, Septic: Additional (http://cast.chesapeakebay.net/FileBrowser/GetFile?fileName=Septic%20System%20Unit%20Costs%20Details%20RTI%20(3).xlsx). Last accessed February 26, 2019.

10. Maldonado, Jerry. 2019. Section Head of the Environmental Programs Section, Department of the Environment, Prince George's County. Personal communication, February 21, 2019 and April 1, 2019.

11. MDE. 2014. Accounting for Stormwater Wasteload Allocations and Impervious Acres Treated: Guidance for NPDES Stormwater Permits. August 2014. https://mde.state.md.us/programs/Water/StormwaterManagementProgram/Documents/NPDES%20MS4%20Guidance%20August%2018%202014.pdf

12. BMP Pounds Reduced and Costs by State.xlsx: CAST, Develop a Plan, Cost Effectiveness of BMPs (http://cast.chesapeakebay.net/FileBrowser/GetFile?fileName=BMP_LbsReducedAndCostsState.xlsx). Last accessed February 28, 2019.

13. Chesapeake Bay Program. 2017. Chesapeake Assessment and Scenario Tool (CAST) Version 2017d. Chesapeake Bay Program Office, Last accessed February 2019.

Section 2. Agricultural BMPs

Introduction

This report section describes methods used to update cost information for a subset of the agricultural best management practices (BMPs) in the Chesapeake Assessment Scenario Tool (CAST) databases. We updated the practices that are used in Maryland by incorporating new data from Maryland and federal sources for Maryland. The report includes information about data sources used, significant assumptions, and methods used to estimate unit costs, operations and maintenance (O&M) costs, opportunity costs, and annual costs.

This report accompanies an Excel spreadsheet that provides average annual costs per unit of practice and cost-efficiencies or cost per pound of nitrogen and phosphorus removed by that practice, using efficiencies available from CAST (as of September 2018). The summary spreadsheet shows a summary of data inputs and results. Costs and cost-efficiencies will update if any of the input data are changed, thereby allowing users to see the effects of alternative assumptions.

Data sources and methods

Multiple data sources were used to estimate BMP costs. The Maryland Agricultural Cost Share (MACS) program data *[14]*[3] were used to estimate average implementation cost and lifespans of the practices that are included in that program (shown in green in summary spreadsheet). For all other practices, implementation costs were drawn from the USDA Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP) data (Maryland Scenarios) *[15]*. The CAST agriculture cost data were used to fill some data gaps including cost-share percentage for EQIP program practices *[16]* and nutrient reduction efficiencies *[17]*. Only some agricultural practices remove land from potential production or farm use and thus incur opportunity costs of land. We used CAST assumptions about the area of land taken out of production *[16]*. Annual Operations and Maintenance (O&M) costs were provided by Jason Keppler (MDA) with input from MACS participants.

NRCS EQIP costs were estimated by selecting the Maryland Practice Scenario that best matched the CAST practice description and was deemed to be the most typical implementation in Maryland (Screenshot 1) *[15]*. NRCS scenarios were matched to the CAST BMP practice name using a crosswalk sheet provided by CAST *[18]* and Jason Keppler (MDA) provided other information inputs. Lifespans for practices not cost-shared by the MACS program were found on the NRCS Maryland Payment Schedules website *[19]*. Unit costs were calculated either by using one scenario or combining multiple NRCS scenarios to best represent CAST BMP descriptions. For example, stream buffer costs were added to exclusion fencing costs to represent the practice in CAST that includes both (Grass Buffer – Streamside with Exclusion Fencing).

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[3] Italicized numbers in brackets refer to references at the end of the report section.

Screenshot 1. Field Crops, Grains, 2nd and 3rd Year Scenario from the NRCS Maryland Payment Schedules: Practice Scenarios *[15]*

USDA - Natural Resources Conservation Service **Maryland**

Practice: 449 - Irrigation Water Management

Scenario #11 - Field Crops, Grains, 2nd and 3rd Year

Scenario Description:

A system to monitor irrigation water applied to field crops over a 19-week growing season. Soil moisture data is reviewed 3 times per week at each sensor site (two sensors per site) with one sensor site per 25 acres. Subscription to real-time weather records and rainfall record keeping is used. The producer must manually turn on and off the water supply in accordance with the soil moisture readings and keep records for each irrigation cycle (run time, inches applied, and total flow recorded). Record keeping involves a weekly analysis, monthly documentation, and a year-end report. Resource Concerns: Insufficient Water Supply-Inefficient use of irrigation water; Degraded Plant Condition-Undesirable plant productivity and health, and Inefficient Energy Use-Equipment and facilities. Associated Practices: 441-Irrigation System Microirrigation, 442-Irrigation System Sprinkler, 443-Irrigation System Surface and Subsurface, 587-Structure for water Control, 328-Conservation Crop Rotation, and 590-Nutrient Management.

Before Situation:

The farmer decides when to irrigate his field crops (ex: corn, soybeans, wheat) based on general crop or soil appearance or limited soil moisture monitoring. System run times are based on past apparent success. The typical irrigated field is a 50 acre corn field with sprinkler irrigation.

After Situation:

Producer has installed 2 sensors at each monitoring site at different depths. Producer uses periodic soil moisture measurements to schedule irrigation more effectively resulting in improved irrigation water managment and reduced energy use. Records are used to evaluate results of past irrigation events and influence future irrigations. The irrigator keeps records of soil moisture, crop water use, rainfall amounts and irrigation timing and amounts. At the end of the irrigation season all the data has been reviewed and evaluated. Improvements planned for the next season have been determined.

Feature Measure: Irrigated Are Managed

Scenario Unit:: Acre

Scenario Typical Size: 50.0

Scenario Total Cost: $455.62

Scenario Cost/Unit: $9.11

Cost Details:

Component Name	ID	Description	Unit	Cost	QTY	Total
Labor						
General Labor	231	Labor performed using basic tools such as power tool, shovels, and other tools that do not require extensive training. Ex. pipe layer, herder, concrete placement, materials spreader, flagger, etc.	Hour	$21.73	4.75	$103.22
Supervisor or Manager	234	Labor involving supervision or management activities. Includes crew supervisors, foremen and farm/ranch managers time required for adopting new technology, etc.	Hour	$44.05	8	$352.40

Scenarios were chosen (Table 17), and were used in the following manner. Cost per unit of BMP was extracted from the scenario and scaled up to 100% of implementation costs, assuming a 75% cost-share (following CAST). The Scenario Typical Size was used to convert total costs into unit costs that matched the CAST accounting units (e.g., acres, systems). An example EQIP practice table is displayed below (Table 18).

Table 17. CAST BMP name and NRCS EQIP scenario matchup [15]

CAST BMP Name	NRCS EQIP Maryland Scenarios			
	NRCS Code	**EQIP Practice Name**	**EQIP Component**	**Scenario #**
Conservation Plan	110	Grazing Management Plan - Written	Grazing Management Plan Less Than or Equal to 100 acres	1
Conservation Tillage	329	Residue and Tillage Management, No-Till	No-Till/Strip-Till	1
High Residue Tillage	330	Residue and Tillage Management, No-Till	No-Till/Strip-Till	2
Cropland Irrigation Management	449	Irrigation Water Management	Field Crops, Grains, 2nd and 3rd Year	11
Horse Pasture Management	110	Grazing Management Plan - Written	Grazing Management Plan Less Than or Equal to 100 acres	1
	512	Forage and Biomass Planting	Overseeding with Nutrient Application	8
Manure Incorporation Low Late	360	Waste Facility Closure	Liquid Waste Impoundment Closure with 75% Liquids and 25% Solids	4
	327	Conservation Cover	Introduced Species	1
Land Retirement to Pasture	327	Conservation Cover	Introduced Species	1
Nutrient Management	590	Nutrient Management	Basic NM with Manure Injection or Incorporation	2
Non Urban Stream Restoration	584	Channel Bed Stabilization	Bioengineering	1
Precision Intensive Rotational/Prescribed Grazing	528	Prescribed Grazing	Pasture Deferment of Interrupted Harvest	3
	110	Grazing Management Plan - Written	Grazing Management Plan Less Than or Equal to 100 acres	1
Tree Planting	612	Tree/Shrub Establishment	Individual Hardwood Trees with Shelters	1

Table 18. Example scenario calculations of BMP implementation cost

EQIP Scenario Cost per System	$455.62
EQIP Cost Share Proportion	0.75
Total Cost per System	$607.49
Typical Size (acres)	50
Unit Cost ($/acre)	$12.15

Land opportunity cost calculations

Opportunity cost of land represents any farm production value given up by adopting a BMP. These costs are represented by cropland rental rates in the cost estimates. MDA provided agricultural land rental rates by county (Table 19) *[20]*. We estimated an average state rental rate by creating an area-weighted average of rental rates. This rate was applied to all practices for which CAST used land opportunity costs (Original Ag BMP Costs spreadsheet) *[16]*.

Table 19. CRP rental rates & average agricultural area data by Maryland county

		Average Agriculture Area by MD County			
Maryland County	**CRP Regular Rental Rate ($/acre-yr)**	**Avg Cropland Area (acres)**	**Avg Hay & Pasture Area (acres)**	**Avg Feeding Space Area (acres)**	**Total Area (acres)**
ALLEGANY	58	3,804	18,289	12	22,105
ANNE ARUNDEL	44	9,968	7,893	31	17,893
BALTIMORE	93	37,602	17,474	73	55,149
CALVERT	42	15,015	5,170	14	20,199
CAROLINE	101	95,774	7,308	200	103,281
CARROLL	106	75,241	38,683	136	114,060
CECIL	103	52,791	15,181	90	68,062
CHARLES	41	20,434	11,411	16	31,861
DORCHESTER	108	89,410	2,996	99	92,505
FREDERICK	80	94,985	64,652	170	159,807
GARRETT	37	16,998	43,658	56	60,711
HARFORD	138	36,524	23,584	70	60,178
HOWARD	73	16,210	7,448	34	23,691
KENT	131	93,678	5,738	46	99,462
MONTGOMERY	50	32,894	14,464	66	47,424
PRINCE GEORGE'S	44	7,290	7,883	56	15,229
QUEEN ANNE'S	125	112,861	5,921	97	118,878
SAINT MARY'S	45	32,232	2,882	216	35,330
SOMERSET	76	30,283	10,564	29	40,876
TALBOT	102	83,895	3,152	41	87,089
WASHINGTON	88	55,707	46,183	126	102,016
WICOMICO	95	53,318	7,313	154	60,786
WORCESTER	88	69,187	2,817	184	72,187
BALTIMORE CITY	92	**1,136,099**	**370,663**	**2,015**	**1,508,777**
Area-Weighted Average	**92.50**				

Annualizing costs

Costs per year were estimated as both a simple division of total costs by lifespan or as an annualized cost using the same accounting methods described for stormwater. (See Annual and annualizing costs in stormwater section above for methods and equations). Annual and annualized costs are summarized in the final summary tables below.

Calculating cost efficiencies

We calculated the cost-effectiveness, or the cost per pound of nutrient reduction, by BMP (Table 20). Nutrient reductions per practice were derived from CAST *[17]*.

Table 20. Pounds of nitrogen and phosphorous reduction per unit of BMP

CAST BMP Full Name	Unit	Lbs N Reduced (EOT)/Unit-Yr	Lbs P Reduced (EOT)/Unit-Yr
Barnyard Runoff Control	# of projects	145.560	9.713
Forest Buffers	acres	61.444	1.63
Grass Buffers	acres	48.278	0.769
Grass Buffer - Narrow with Exclusion Fencing	acres	43.722	11.575
Grass Buffer - Streamside with Exclusion Fencing	acres	155.005	41.517
Land Retirement to Open Space	acres	18.646	0.145
Loafing Lot Management	acres	145.560	9.713
Off Stream Watering Without Fencing - Troughs	acres	0.408	0.058
Wetland Restoration - Headwater	acres	37.879	1.247
Water Control Structures	acres	5.982	0
Animal Waste Management System - Livestock	animal units	0.766	0.050
Manure Transport	dry tons	3.240	0.530
Conservation Plan	acres	1.354	0.085
Conservation Tillage	acres	1.425	0.190
High Residue Tillage	acres	1.425	0.190
Cropland Irrigation Management	acres	0.853	0
Horse Pasture Management	acres	0	0.146
Manure Incorporation Low Late	acres	1.705	0.116
Land Retirement to Pasture	acres	16.440	0.198
Nutrient Management	acres	0.594	0.034
Non Urban Stream Restoration	linear feet	0.059	0.046
Precision Intensive Rotational/Prescribed Grazing	acres	0.825	0.175
Tree Planting	acres	20.220	0.691

Final summary tables

Table 21 shows the annual and annualized costs per unit of BMP that were calculated in this analysis compared with annualized costs from CAST *[21]*. Most of the cost estimates in this analysis were higher, while estimated costs were lower for a quarter of the practices. Updating the O&M values had a large effect on the estimated cost increases, while the updated lifespans and opportunity costs of land had a smaller effect. The lower costs for some practices can be attributed to these changes, and in some cases, differences in costs may be due to different matching of EQIP practice to CAST practice. Costs, cost-effectiveness and input data are summarized in Table 22 by CAST BMP names.

Table 21. Average annual costs from this analysis compared with average annual costs from CAST

CAST BMP Full Name	Unit	Average Annualized Unit Cost – this analysis	Average Annualized Unit Cost – CAST	Percent change from CAST
Barnyard Runoff Control	# of projects	$942.43	$446.45	111%
Forest Buffers	acres	$361.71	$100.33	261%
Grass Buffers	acres	$141.48	$40.97	245%
Grass Buffer - Narrow with Exclusion Fencing	acres	$1,855.72	$702.37	168%
Grass Buffer - Streamside with Exclusion Fencing	acres	$662.69	$261.32	154%
Land Retirement to Open Space	acres	$188.43	$168.87	12%
Loafing Lot Management	acres	$38,220	$168.87	22,533%
Off Stream Watering Without Fencing - Troughs	acres	$760.67	$29.53	2,476%
Wetland Restoration - Headwater	acres	$602.30	$343.85	75%
Water Control Structures	acres	$82.79	$17.74	367%
Animal Waste Management System - Livestock	animal units	$100.68	$181.51	-45%
Manure Transport	dry tons	$15.41	$27.53	-44%
Conservation Plan	acres	$49.29	$1.94	2,441%
Conservation Tillage	acres	$22.94	$0	NA
High Residue Tillage	acres	$22.94	$0	NA
Cropland Irrigation Management	acres	$12.76	$135.06	-91%
Horse Pasture Management	acres	$96.51	$21.77	343%
Manure Incorporation Low Late	acres	$56.67	$17.34	227%
Land Retirement to Pasture	acres	$155.32	$168.87	-8%
Nutrient Management	acres	$50.11	$0	NA
Non Urban Stream Restoration	linear feet	$18.27	$6.84	167%
Precision Intensive Rotational/Prescribed Grazing	acres	$245.29	$14.67	1,572%
Tree Planting	acres	$442.36	$84.06	426%

Implementation costs for practices shaded in green were derived from the Maryland Agricultural Cost-Share (MACS) program. Implementation costs for unshaded practices were derived from EQIP.

Table 22. Summary of agricultural BMP costs by CAST BMP name

CAST BMP Full Name	Count	Lifespan (yrs)	Implementation Unit Cost			Units	Annual O&M Costs	Simple Annual Unit Cost		Annualized Unit Cost		Cost Efficiency	
			Minimum	Maximum	Average			No land costs	With land costs (if applicable)	No land costs	With land costs (if applicable)	$/lb of N (EOT) reduction	$/lb of P (EOT) reduction
Barnyard Runoff Control	85	10	$250.34	$30,644.39	$7,084.15	# of projects	$25.00	$733.41	$733.41	$942.43	$942.43	$6.47	$97.02
Forest Buffers	126	10	$375.00	$2,973.63	$2,001.55	acres	$10.00	$210.16	$302.65	$269.21	$361.71	$5.89	$221.91
Grass Buffers	66	10	$38.13	$500.00	$301.02	acres	$10.00	$40.10	$132.60	$48.98	$141.48	$2.93	$184.01
Grass Buffer - Narrow with Exclusion Fencing	169	10	NA	NA	$14,522.39	acres	$5.00	$1,457.24	$1,457.72	$1,885.72	$1,885.72	$43.13	$162.91
Grass Buffer - Streamside with Exclusion Fencing	NA	10	NA	NA	$4,364.27	acres	$5.00	$441.43	$533.92	$570.19	$662.69	$4.28	$15.96
Land Retirement to Open Space	47	10	$93.73	$3,042.86	$547.75	acres	$25.00	$79.77	$172.27	$95.94	$188.43	$10.11	$1,301.14
Loafing Lot Management	61	10	$10,702	$3,237,093	$294,933.27	acres	$25.00	$29,518	$29,518	$38,220	$38,220	$262.57	$3,934.75
Off Stream Watering Without Fencing - Troughs	100	10	$940.44	$27,295.62	$5,680.68	acres	$25.00	$593.07	$593.07	$760.67	$760.67	$1,863.53	$13,144.54
Wetland Restoration - Headwater	23	15	$266.41	$17,730.70	$5,032.11	acres	$25.00	$360.47	$452.97	$509.80	$602.30	$15.90	$482.83
Water Control Structures	16	10	$69.92	$583.84	$253.16	acres	$50.00	$75.32	$75.32	$82.79	$82.79	$13.84	-
Animal Waste Management System - Livestock	87	15	$12.81	$2,553.47	$1,045.03	animal units	$-	$69.67	$69.67	$100.68	$100.68	$131.44	$1,994.86
Manure Transport	3050	1	$-	$141.60	$14.68	dry tons	$-	$14.68	$14.68	$15.41	$15.41	$4.76	$29.09
Conservation Plan	NA	1	NA	NA	$46.94	acres	$-	$46.94	$46.94	$49.29	$49.29	$36.41	$579.56
Conservation Tillage	NA	1	NA	NA	$21.85	acres	$-	$21.85	$21.85	$22.94	$22.94	$16.10	$120.46

CAST BMP Full Name	Count	Lifespan (yrs)	Implementation Unit Cost			Units	Annual O&M Costs	Simple Annual Unit Cost		Annualized Unit Cost		Cost Efficiency	
			Minimum	Maximum	Average			No land costs	With land costs (if applicable)	No land costs	With land costs (if applicable)	$/lb of N (EOT) reduction	$/lb of P (EOT) reduction
High Residue Tillage	NA	1	NA	NA	$21.85	acres	$-	$21.85	$21.85	$22.94	$22.94	$16.10	$120.46
Cropland Irrigation Management	NA	1	NA	NA	$12.15	acres	$-	$12.15	$12.15	$12.76	$12.76	$14.95	-
Horse Pasture Management	NA	5	NA	NA	$352.88	acres	$15.00	$85.58	$85.58	$96.51	$96.51	-	$660.86
Manure Incorporation Low Late	NA	1	NA	NA	$53.97	acres	$-	$53.97	$53.97	$56.67	$56.67	$33.23	$489.31
Land Retirement to Pasture	NA	5	NA	NA	$163.75	acres	$25.00	$57.75	$150.25	$62.82	$155.32	$9.45	$784.83
Nutrient Management	NA	1	NA	NA	$47.73	acres	$-	$47.73	$47.73	$50.11	$50.11	$84.33	$1,470.04
Non Urban Stream Restoration	NA	10	NA	NA	$133.36	linear feet	$1.00	$14.34	$14.34	$18.27	$18.27	$308.84	$396.42
Precision Intensive Rotational/Prescribed Grazing	NA	1	NA	NA	$219.33	acres	$15.00	$234.33	$234.33	$245.29	$245.29	$297.36	$1,400.40
Tree Planting	NA	15	NA	NA	$3,527.70	acres	$10.00	$245.18	$337.68	$349.87	$442.36	$21.88	$639.93
											Average	**$143.50**	**$1,336.01**
											Median	**$16.00**	**$489.31**

Implementation costs for practices shaded in green were derived from the Maryland Agricultural Cost-Share (MACS) program. Implementation costs for unshaded practices were derived from EQIP.

Data Sources for Agricultural Practices

14. WIP_Costs.xlsx. Personal communication with Jason Keppler (MDA). (January 11, 2019).

15. Maryland_Scenarios. NRCS Maryland Payment Schedules: Practice Scenarios. Available online: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/financial/?cid=nrcseprd1328242. (Downloaded January 17, 2019).

16. Ag BMP Unit Costs.xlsx: CAST, Public Reports, Cost Profiles, BMP Cost Data Sources, Agricultural: Original (https://cast.chesapeakebay.net/Documentation/CostProfiles). Downloaded January 15, 2019. Last updated April 2, 2013.

17. BMP Pounds Reduced and Costs by State.xlsx: CAST, Develop a Plan, Cost Effectiveness of BMPs (http://cast.chesapeakebay.net/FileBrowser/GetFile?fileName=BMP_LbsReducedAndCostsState.xlsx). Last accessed February 28, 2019.

18. NRCS_CAST_BMPs.xlsx: CAST, Develop a Plan, Nomenclature, NRCS Practices and CAST BMPs (https://cast.chesapeakebay.net/Documentation/BMPsModelsGeography). Downloaded January 15, 2019.

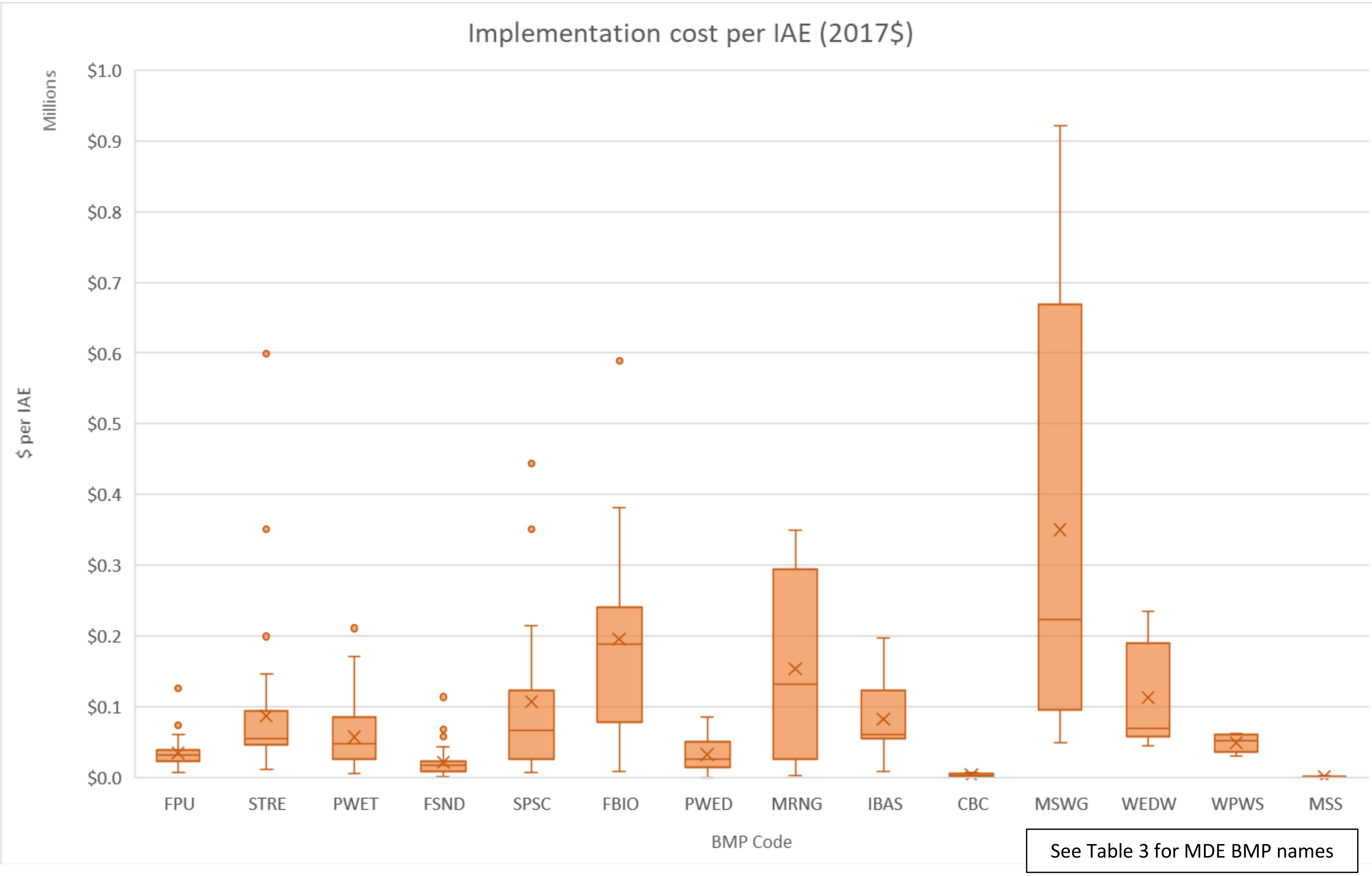
19. NRCS_EQIP_Code_Practice_Lifespans. Available online: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1076947.pdf. (Downloaded January 17, 2019).

20. 2018 CRP Rental Rates and Average Agriculture Area by MD County. Personal Communication with Alisha Mulkey (MDA) (January 11, 2019).

21. Maryland_BmpCosts.xlsx: CAST, Public Reports, Cost Profiles, Maryland (https://cast.chesapeakebay.net/Documentation/CostProfiles). Downloaded September 4, 2018.

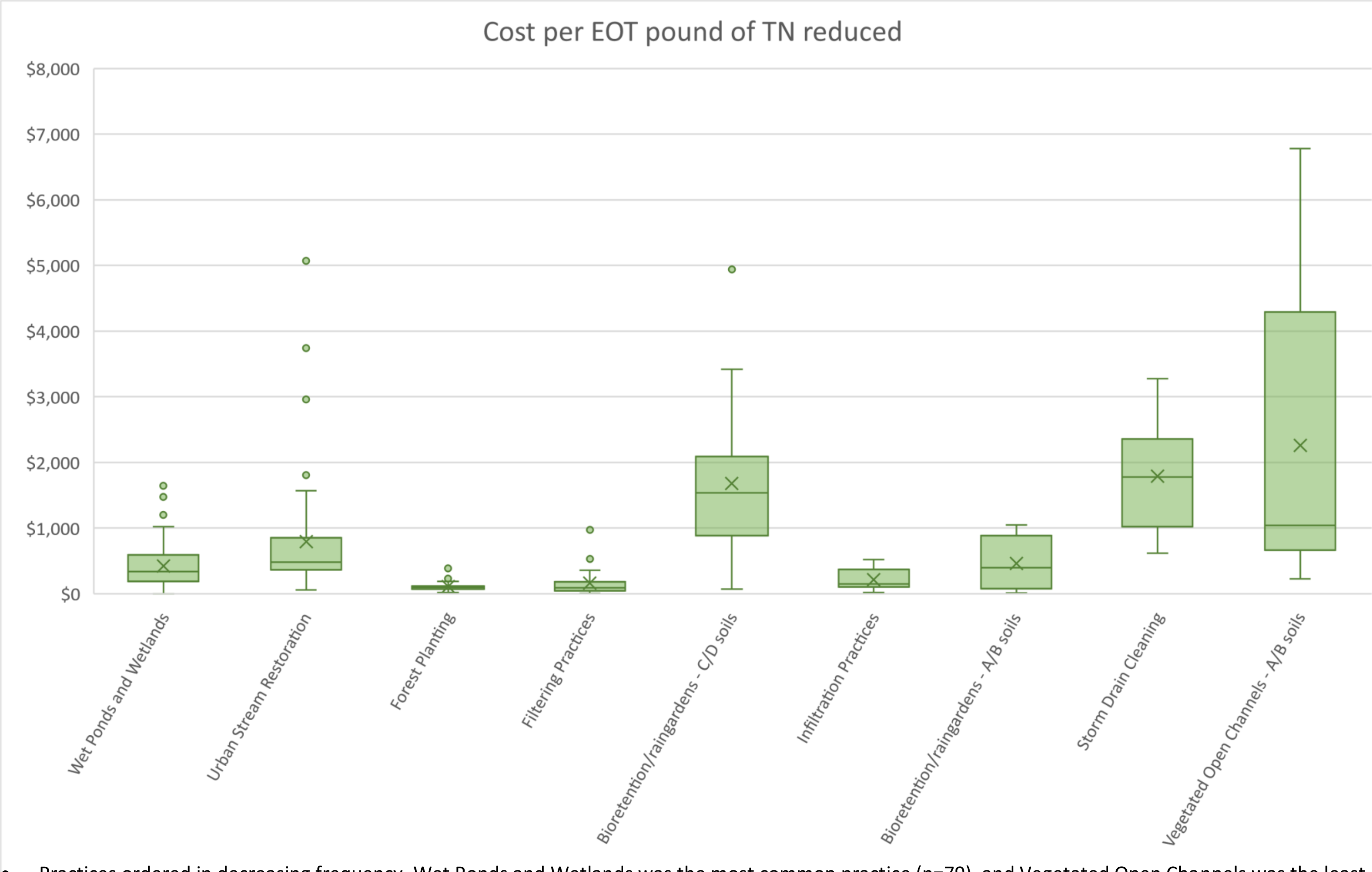
Appendix – Box and Whisker Plots

Figure A-1. Box and whiskers plot of annual implementation costs per IAE for all stormwater BMPs with at least 5 records in the UMCES-derived database



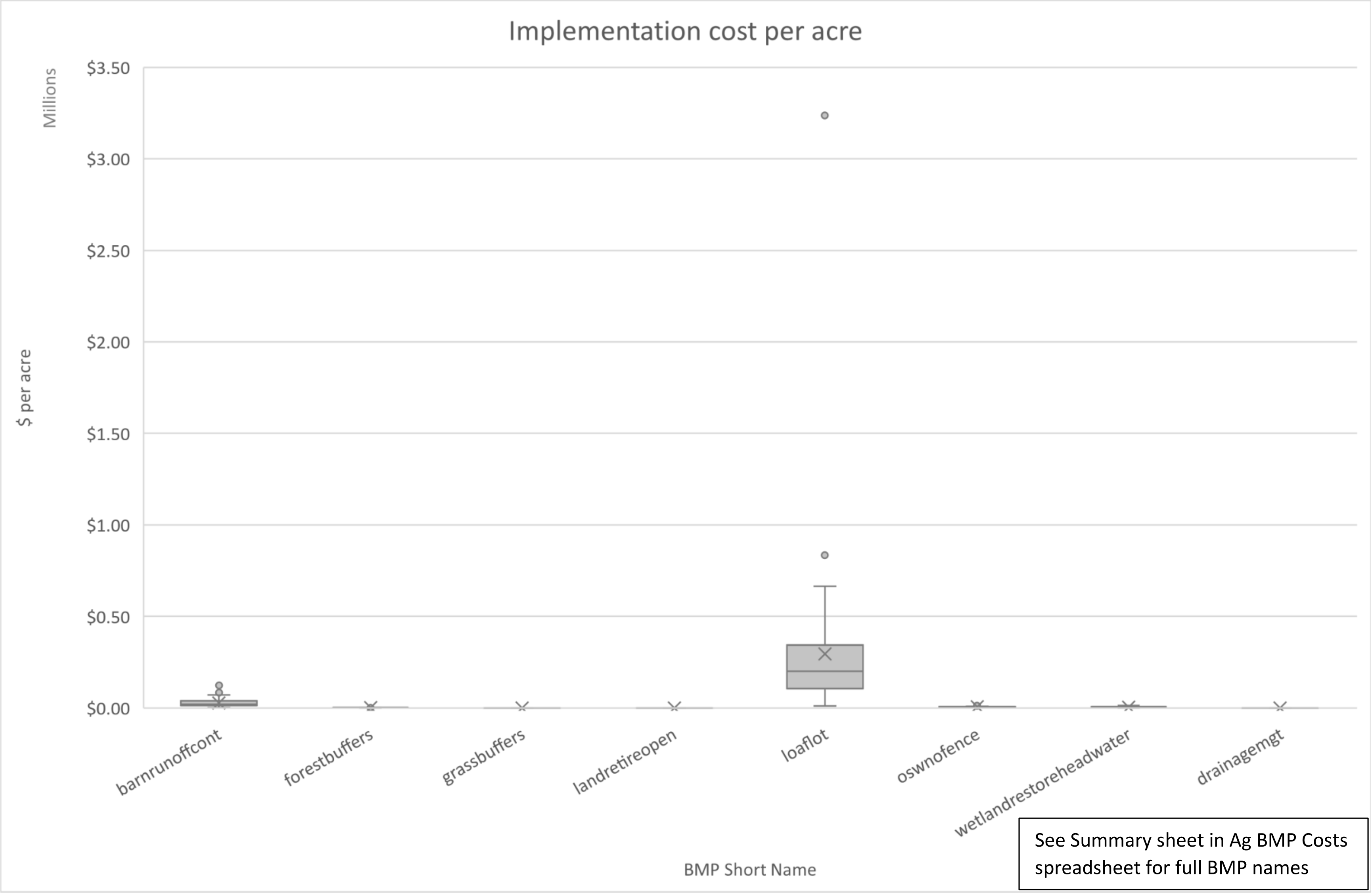
- The "x" symbol in each plot denotes the mean value, and the circles show the outliers.
- Practices ordered in decreasing frequency. FPU was the most common (n=72), and CBC, MSWG, WEDW, WPWS and MSS were the least common (n=5).
- Two extreme outliers were removed (approximately $1.8 million/IAE for FPU and SPSC).

Figure A-2. Box and whiskers plot of cost efficiency of N removal for CAST stormwater BMPs with at least 5 records in the UMCES-derived database



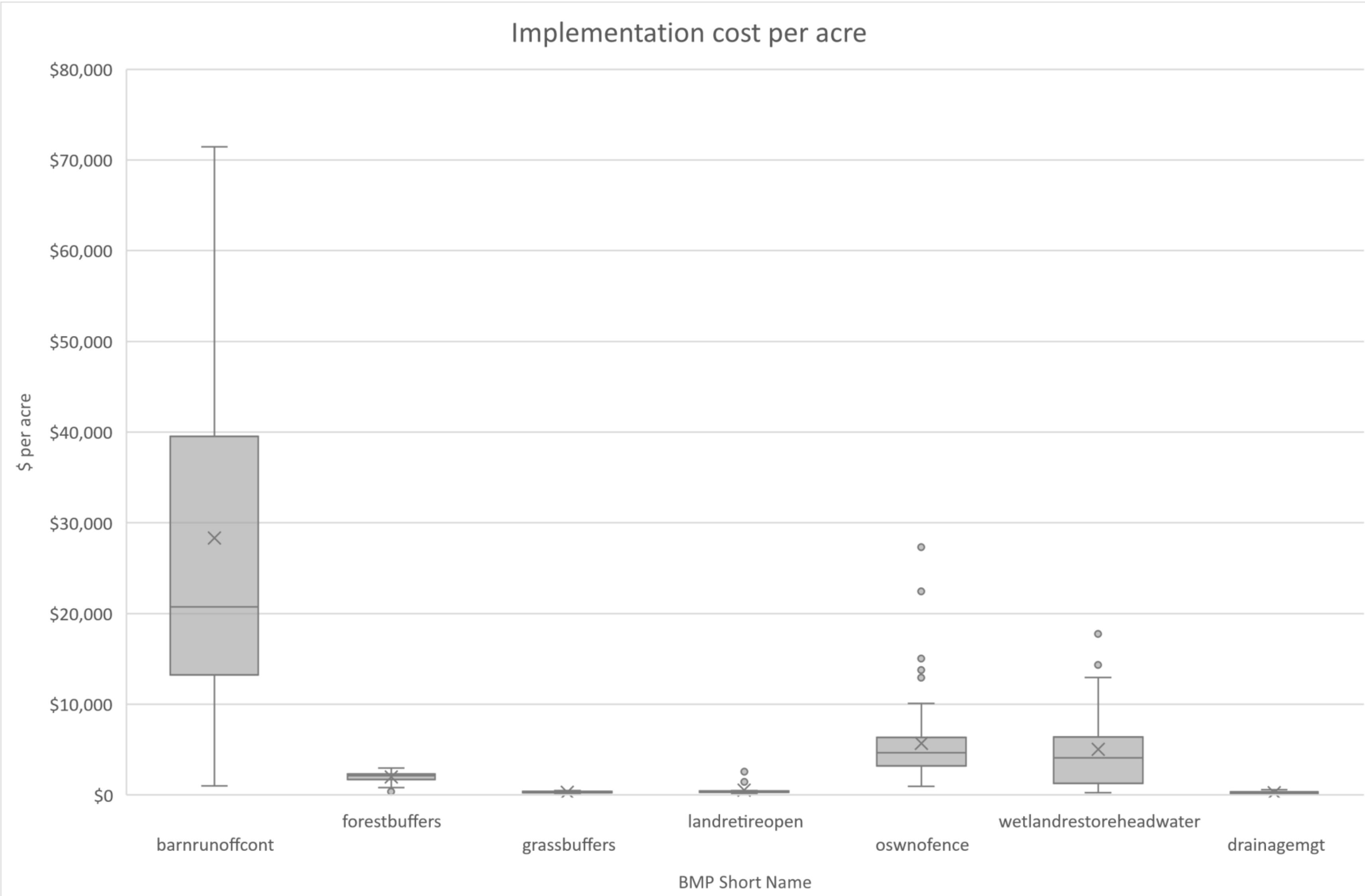
- Practices ordered in decreasing frequency. Wet Ponds and Wetlands was the most common practice (n=79), and Vegetated Open Channels was the least common (n=5).
- Four extreme outliers were removed ($32,000/lb and $15,000/lb for Stream Restoration; $5,500/lb for Forest Planting; $47,000/lb for Bioretention/Rain gardens – C/D soils).
- Annual costs were calculated by dividing the implementation cost of each project by the estimated lifespan of the practice. Opportunity and annual O&M costs were not included because they were calculated from median implementation costs, not project-specific costs.

Figure A-3. Box and whiskers plot of agricultural BMP annual implementation costs (for practices measured in acres)



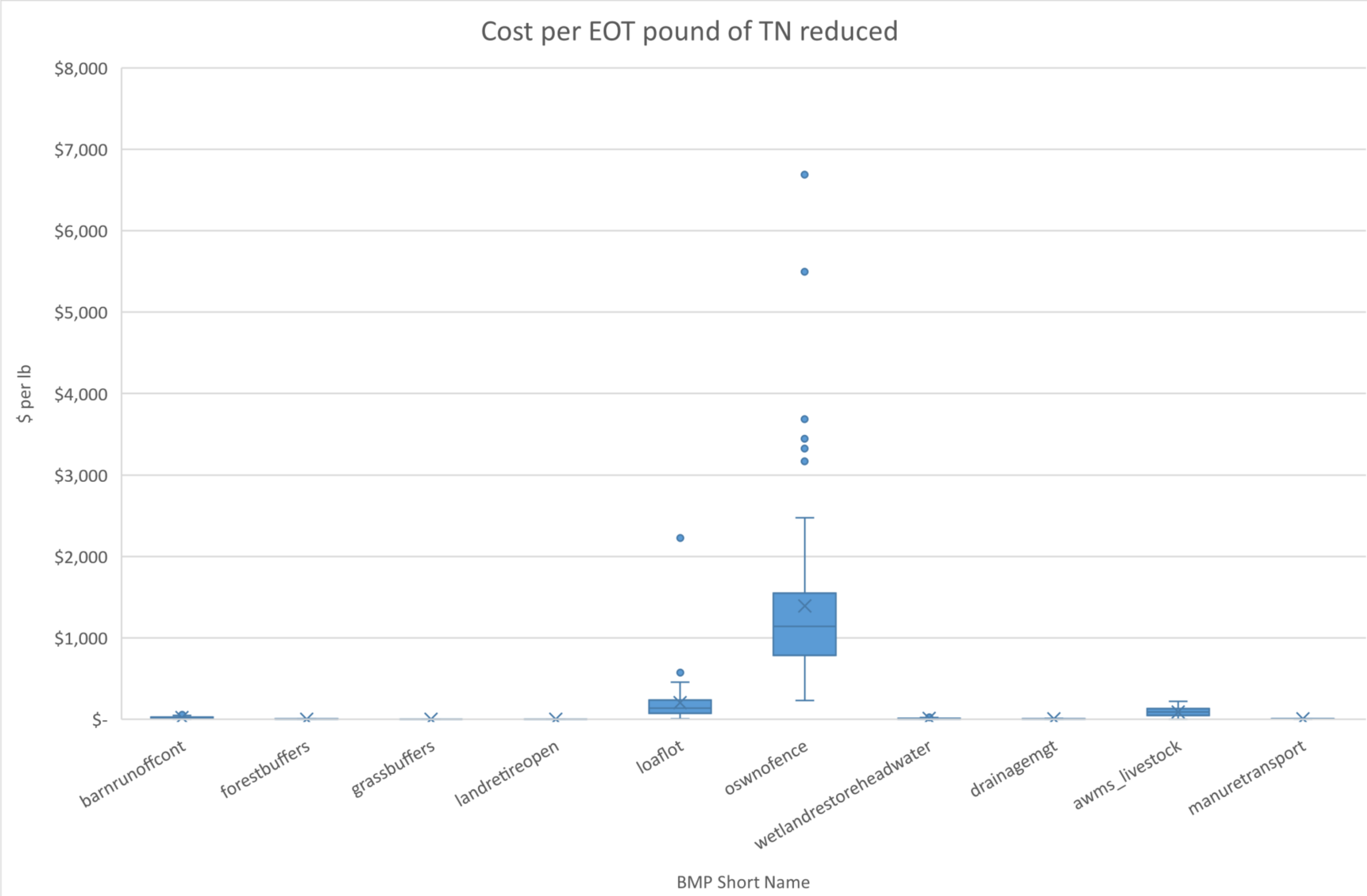
See Summary sheet in Ag BMP Costs spreadsheet for full BMP names

Figure A-4. Box and whiskers plot of agricultural BMP annual implementation costs (for practices measured in acres, loaflot removed)



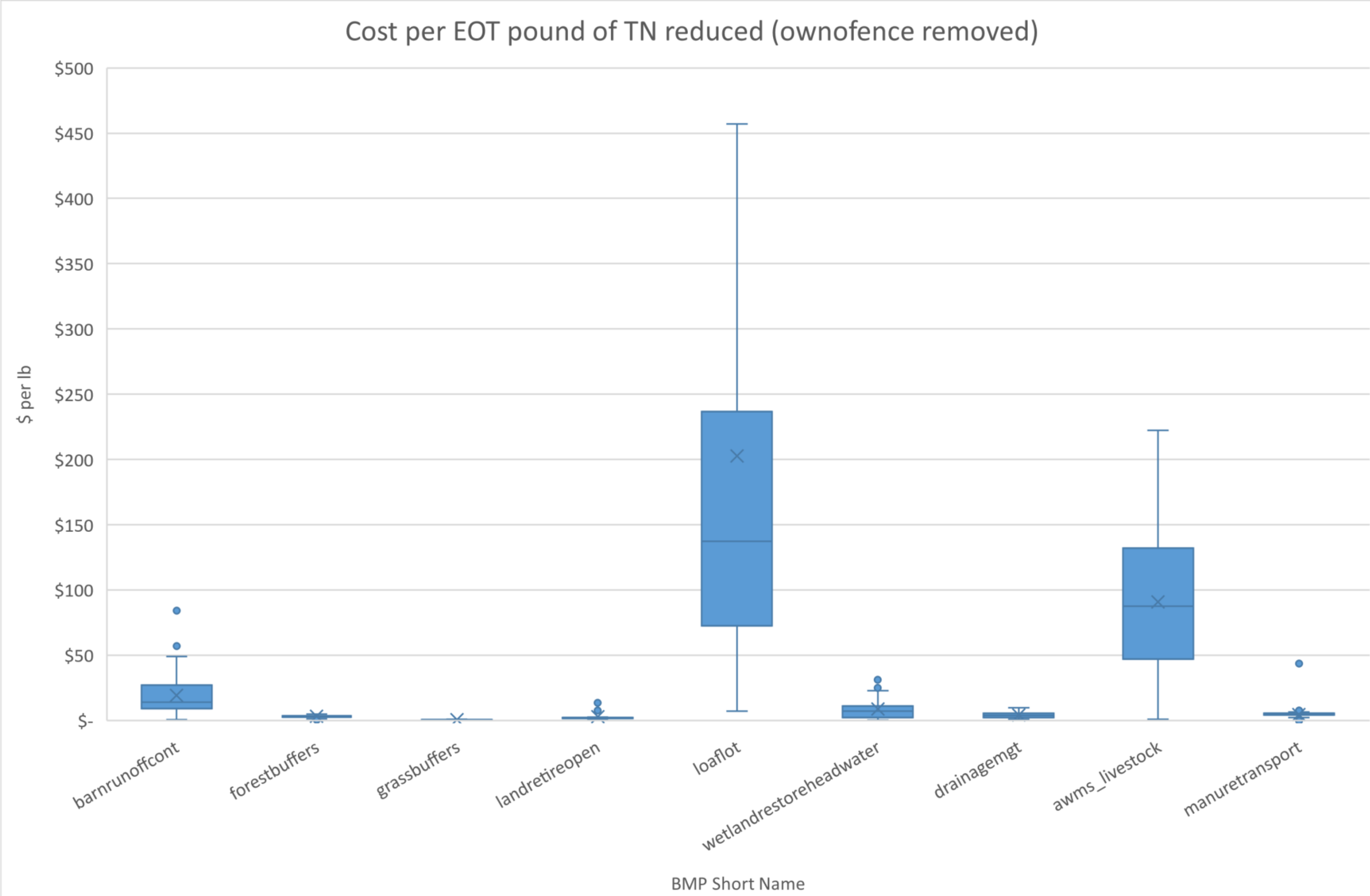
- Four extreme outliers were removed ($83,278/lb, $85,341/lb, $89,835/lb, and $122,578/lb for barnrunoffcont).

Figure A-5. Box and whiskers plot of agricultural BMP nitrogen removal cost efficiency (all practices)



- Annual costs were calculated by dividing the implementation cost of each project by the estimated lifespan of the practice. Opportunity and annual O&M costs were not included because they were calculated from average implementation costs, not project-specific costs.

Figure A-6. Box and whiskers plot of agricultural BMP nitrogen removal cost efficiency (oswofence removed)



- Two extreme outliers were removed ($2,224/lb and $573/lb for loaflot).
- Annual costs were calculated by dividing the implementation cost of each project by the estimated lifespan of the practice. Opportunity and annual O&M costs were not included because they were calculated from average implementation costs, not project-specific costs.