User Manual for the Clean Water Optimization Tool

Eastern Shore, Maryland Version 1.0

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Center for Watershed Protection

3290 North Ridge Road, Suite 290

Ellicott City, MD 21043

www.cwp.org

Contents

1. Background

Communities on the Eastern Shore of Maryland face some unique challenges with developing stormwater pollution reduction strategies to meet the Chesapeake Bay total maximum daily load (TMDL) requirements. Each county was tasked with developing a Phase II Watershed Implementation Plan (WIP) that outlines how they will achieve the TMDL reductions, which will be enforced through the National Pollution Discharge and Elimination System (NPDES) municipal separate storm sewer system (MS4) permit program. Only two Eastern Shore municipalities are currently regulated under the MS4 program, leaving the rest uncertain of their legal obligation to reduce nutrient and sediment loads. There is also some uncertainty about whether the resulting WIP strategies can actually be implemented given the high price tag associated with them. For example, the estimated cost to implement Somerset County's WIP is $960 million through 2025, or more than $36,000 per resident (Somerset County Board of County Commissioners, 2012).

Reasons for the high estimated WIP costs include the cost data used to develop the assumptions and the types of stormwater best management practices (BMPs) included in the WIPs. Many Maryland WIPs rely on implementation of stormwater BMPs as retrofits, which are often suggested as the best way to achieve stormwater pollution reductions. However, the cost to construct retrofits can be quite high since they often require modifying existing infrastructure and the feasibility of implementing certain types of stormwater BMPs is limited on the Eastern Shore due to the potentially high groundwater table and often poor draining soils. While stormwater retrofits are important, other BMPs such as stream restoration or tree planting may be much more cost-effective and applicable on the Eastern shore, yet it is likely neither cost-effectiveness nor feasibility of implementation were factors in developing the WIPs. Lastly, available cost data for stormwater BMPs is highly variable and does not typically reflect local conditions.

To help the Eastern Shore counties develop more realistic and cost-effective WIP scenarios, the Center for Watershed Protection developed the Clean Water Optimization Tool with a grant from the Town Creek Foundation. Project partners included: Choose Clean Water Coalition, Kent County, Queen Anne's County, Talbot County, Wicomico County, and the Chesapeake Bay Foundation. This User Manual describes how to use the Tool, which is available at www.cwp.org.

2. Overview

2.1. What is the Clean Water Optimization Tool?

The Clean Water Optimization Tool (Tool) is a planning tool for Maryland Eastern Shore communities to develop cost-effective stormwater BMP scenarios for meeting Chesapeake Bay TMDL WIP goals (see Figure 1 for a Tool overview). For each scenario, the Tool provides the following results:

1. the number of units treated by each selected BMP
2. the estimated total (and per-BMP) annual total nitrogen (TN), total phosphorus (TP) and total suspended sediment (TSS) load reductions
3. the estimated total (and per-BMP) annual cost

The Tool's optimization feature allows a community to easily and quickly select the most cost-effective suite of BMPs and users can compare results across scenarios.

Clean Water Optimization Tool

Base Data	**Inputs for Scenario Development**	**Outputs**
• Required pollutant reductions • BMPs • BMP costs • Land use/pollutant loading rates and BMP efficiencies	Define Scale and Scope: • Geographic scale • Time Frame Define Model Constraints: • Maximum area that can feasibly treated by each BMP • Whether to include all BMPs or only Chesapeake Bay Program "approved" BMPs Define Goals: • Pollutant on which to base the optimization • Priority BMPs • Reductions from BMPs implemented since 2009	• Units treated by each BMP • Total and per-BMP annual pollutant reduction • Total and per-BMP annual cost

Figure 1. Clean Water Optimization Tool data requirements and outputs

The Tool results are for planning purposes only and should not be used to develop detailed budgets or capital improvement project plans. Communities are encouraged to conduct desktop and field assessments to identify specific locations for stormwater BMPs to increase the reliability of the Tool results. Guidance on conducting these assessments is provided in Section 3.1.

2.2. How is the Tool Different from MAST?

Similar to the Clean Water Optimization Tool, the Maryland Assessment and Scenario Tool (MAST, http://www.mastonline.org) allows users to rapidly develop scenarios with various BMPs, and provides outputs of TN, TP and TSS loads, units treated by each BMP, and costs for the scenario. Unlike MAST, the Clean Water Optimization Tool:

1. incorporates a full suite of BMPs, including ones not currently credited in the Chesapeake Bay Watershed Model (credits for some of these BMPs are currently under development, while others are not yet available but show promise for significantly reducing the costs to achieve the WIP goals)

2. allows the user to optimize BMP selection based on cost-effectiveness for a particular pollutant

3. incorporates assumptions about the practicality of installing each type of BMP, so that the resulting scenarios are more realistic and achievable

4. reports pollutant loads reductions for each BMP, and compares total load reductions to the TMDL targets

5. includes cost data that has been adjusted for the Eastern Shore counties

6. allows the user to enter BMP cost when local data are available

7. allows the user to define the scale of the scenario (i.e., County, watershed, municipality)

8. focuses solely on the stormwater sector, and does not include BMPs for agriculture, forestry or wastewater at this time (although it does provide the option to track loads from agricultural land that are treated by BMPs located on urban land).

9. does not account for any land use changes or BMPs associated with new development (stormwater BMPs are applied to untreated/undertreated developed land as retrofits)

The Tool relies on the land use/pollutant loading rates used in MAST but uses pollutant reduction credits recommended by the CBP Stormwater Retrofit Expert

Panel (Schueler and Lane, 2012) for many of those BMPs included in the Chesapeake Bay Watershed Model. The Tool can be used to develop strategies which can be entered into MAST, with the caveat that not all of the BMPs and recently updated credits will be available in MAST. To calculate credit for BMP implementation, communities can use the process described in Section 4 of this document, and will need to report BMPs as required by the Maryland Department of the Environment.

2.3. Data Inputs

To develop a BMP scenario using the Tool, the following data inputs are required:

1. county of interest
2. timeframe for meeting the pollutant reduction targets (2017 or 2025)
3. NPDES regulatory status
4. maximum practical number of units that can be treated by each BMP
5. for certain BMPs, the percent impervious cover in the drainage area to the practice
6. pollutant on which to base the optimization (TN, TP, TSS or TN & TP)

In addition, if the "User-Defined BMP" is selected, pollutant removal efficiencies and cost will need to be entered. Section 3.1 provides guidance on how to estimate the maximum practical number of units that can be treated by each BMP.

Optional data inputs include: user-defined pollutant load reduction goals for running scenarios at a scale other than the county scale, program budget, priority BMPs to receive higher weight in the optimization process, portion of load reductions to be met through trading, and load reductions from BMPs installed between 2013 and the present that have not yet been accounted for in the Chesapeake Bay Watershed Model.

Most defaults in the Tool can be overridden when better local data are available, including BMP costs, assumptions regarding drainage area imperviousness for certain BMP types, and assumptions regarding land values and the proportion of land that is typically developable.

3. How to Use the Tool

The Tool is a Microsoft Excel spreadsheet that consists of eight worksheets:

1. An Instructions sheet that provides an overview of the Tool and basic instructions for its use
2. A Scenario Setup sheet to set up each scenario
3. A BMP Costs sheet that can be customized with locally available data if preferred/available
4. An Optimization Results sheet to select which pollutant to optimize on, and view the scenario results
5. Cost Result Chart, Nitrogen Result Chart, Phosphorus Result Chart and Sediment Result Chart sheets that display the proportion of the total pollutant load reduced and the cost by BMP type

In each worksheet, required input cells are shown in YELLOW. BLUE cells are optional inputs or contain defaults that can be overridden if preferred. To create a scenario using the Tool, follow the steps below and save the spreadsheet as a new file with a name that describes your scenario. Each subsequent scenario you create should be saved as a new Excel file with a unique name.

3.1. Step 1: Scenario Setup

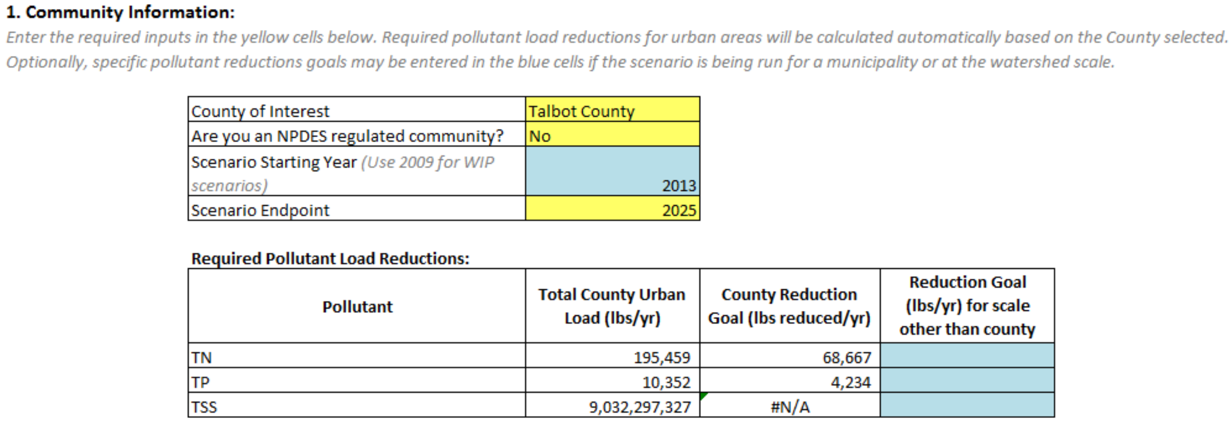
Community Information

The Community Information section of the Scenario Setup worksheet includes three required entries and one optional input. Required inputs include:

1. the county of interest (select from a dropdown list of Maryland Eastern Shore counties)
2. NPDES regulatory status (yes/no)
3. Scenario endpoint (2017 or 2025) by which to achieve Chesapeake Bay TMDL targets (the assumed starting point for the scenarios is 2013)

There is an option to change the scenario starting point to 2009, for users who want to develop a new (or comparison) WIP scenario, as opposed to developing a scenario to achieve the reductions remaining as of 2013. Once the county of interest and the scenario timeframe are entered, the Total County Load (delivered) and County Reduction Goal (in lbs/year for TN, TP, and TSS) will automatically populate (shown in Figure 2) based on the 2009 or 2013 urban loads and the 2017 and 2025 targets for each County from Maryland Department of the Environment: http://baystat.maryland.gov/causes-of-the-problems-map/.

Optionally, the user may enter a different value in the Reduction Goal column to develop a scenario for achieving a user-defined set of nutrient and sediment reductions. An example of when this option would be useful is when developing BMP scenarios for a municipality or a sub-watershed within a county, as opposed to the county scale. The Reduction Goal column may also be used to enter a target associated with a local nitrogen, phosphorus or sediment TMDL.



1. Community Information:

Enter the required inputs in the yellow cells below. Required pollutant load reductions for urban areas will be calculated automatically based on the County selected. Optionally, specific pollutant reductions goals may be entered in the blue cells if the scenario is being run for a municipality or at the watershed scale.

County of Interest	Talbot County
Are you an NPDES regulated community?	No
Scenario Starting Year *(Use 2009 for WIP scenarios)*	2013
Scenario Endpoint	2025

Required Pollutant Load Reductions:

Pollutant	Total County Urban Load (lbs/yr)	County Reduction Goal (lbs reduced/yr)	Reduction Goal (lbs/yr) for scale other than county
TN	195,459	68,667	
TP	10,352	4,234	
TSS	9,032,297,327	#N/A	

Figure 2. Community Information section of the Scenario Setup worksheet

Best Management Practices

In the Best Management Practices section of the Scenario Setup worksheet, the user must enter the maximum practical number of units that can be treated by each BMP that will be included in the scenario. BMPs for which crediting approaches have been approved by the Chesapeake Bay Program (CBP) are shown in GREEN, and BMPs that are not currently given credit are shown in GRAY in the spreadsheet. The BMPs are grouped into three primary categories:

1. stormwater retrofits, most of which are credited based on pollutant removal efficiencies derived from retrofit adjustor curves as described in Schueler and Lane (2012)

2. land use change BMPs, which are credited based on the difference in pollutant loading rates for the two land use types in question (i.e., tree planting involves a change from urban pervious land to forest land)
3. municipal programs and other practices, which include programmatic strategies as well as structural BMPs and have unique crediting formulas

Table 1 presents the stormwater retrofit options included in the Tool, with a definition and the units treated. For these BMPs (with the exception of Extended Detention Ponds), pollutant removal effectiveness was determined using retrofit adjustor curves developed by the CBP Stormwater Retrofit Expert Panel (Schueler and Lane, 2012), which are described further in Section 4. An important note about these credits is that while the panel recommendations have been approved by the CBP, they have not yet been incorporated into MAST. It is assumed that the BMPs in Table 1 will be applied as new retrofits to developed land that has inadequate or no stormwater treatment.

Table 1. Stormwater Retrofit Options Included in the Clean Water Optimization Tool

BMP	**Definition**	**Units Treated**	**Credited by CBP?**
Permeable pavement	Concrete or asphalt pavement that allows water to filter through open voids in the pavement surface	Impervious acres	Yes
Permeable pavers	Pavers, which tend to be associated with residential applications, that allow water to filter through the soil media between the pavers	Impervious acres	Yes
Rainwater harvesting	Capture and storage of rooftop runoff with rain barrels or cisterns for use in outdoor landscaping irrigation, car washing, or non-potable water supply	Impervious acres	Yes
Stormwater planter	On-site vegetated planters that capture, store and filter rainwater through the planting soil and gravel media below, where it infiltrates into native soils	Impervious acres	Yes
Green roof	Alternative roofing surfaces that replace conventional construction materials and include a protective covering of planting media and vegetation	Impervious acres	Yes
Downspout disconnection	Redirection of downspout from impervious cover or storm drain to grass area	Impervious acres	Yes
Bioretention	An excavated pit backfilled with engineered media, topsoil, mulch, and vegetation where stormwater runoff is temporarily ponded and filtered through the bed components. It is assumed that bioretention on the Eastern Shore will be applied primarily in a suburban setting.	Acres	Yes
Rain garden	A shallow, excavated landscape feature that temporarily holds runoff for a short period of time and consists of an absorbent-planted soil bed, a mulch layer, and planting materials.	Acres	Yes

Table 1. Stormwater Retrofit Options Included in the Clean Water Optimization Tool

BMP	**Definition**	**Units Treated**	**Credited by CBP?**
Green streets	Landscaped streetside bioretention or swales that capture stormwater runoff and allow it to filter through the bed components. On the Eastern Shore, these practices will be applied primarily in a highly urban settings.	Acres	Yes
Vegetated filter strips	An area planted with perennial grasses or other low-growing dense vegetation to remove sediment and other pollutants from stormwater runoff flowing through it as sheetflow	Acres	Yes
Hydrodynamic structures and filtering practices	Proprietary devices designed to improve quality of stormwater using features such as swirl concentrators, grit chambers, oil barriers, baffles, micropools, organic filters, and absorbent pads that are designed to remove sediments, nutrients, metals, organic chemicals, or oil and grease from urban runoff.	Acres	Yes
Infiltration practices	A depression to form an infiltration basin where sediment is trapped and water infiltrates the soil (includes dry wells). No underdrains are associated with infiltration basins and trenches, because by definition these systems provide complete infiltration.	Acres	Yes
Tree pits/structural soils	Street trees that are engineered to capture and treat stormwater runoff using an underground trench filled with structural soil media that connects the individual tree pits	Impervious acres	Yes
Sand filter	Practices that capture and temporarily store runoff and pass it through a filter bed of sand	Acres	Yes
Bioswale/dry swale	A linear form of bioretention used to partially treat water quality, attenuate flooding potential and convey stormwater away from critical infrastructure.	Acres	Yes
Wet swale	An open drainage channel or depression, explicitly designed to retain water or intercept groundwater for water quality treatment	Acres	Yes
Vegetated open channels	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.	Acres	Yes
Regenerative Stormwater Conveyance	Regenerative Conveyance Systems are used at eroded or degraded outfalls and drainage channels and incorporate a series of shallow aquatic pools, riffle weir grade controls, native vegetation and underlying sand and sometimes woodchip beds.	Acres	Yes
Wet ponds	A land depression or impoundment created for the detention or retention of stormwater runoff	Acres	Yes
Constructed wetlands	Shallow, constructed pools that capture stormwater and allow for the growth of characteristic wetland vegetation	Acres	Yes

Table 1. Stormwater Retrofit Options Included in the Clean Water Optimization Tool			
BMP	**Definition**	**Units Treated**	**Credited by CBP?**
Extended detention ponds	Depressions created by excavation or berm construction that temporarily store runoff and release it slowly via a small orifice or gravel packed perforated drain following storms. Dry ED basins are designed to dry out between storm events, in contrast with wet ponds, which contain standing water permanently.	Acres	Yes
Ditch enhancement	Conversion of a roadside or agricultural drainage ditch to a bioswale or dry swale	Acres	No
Conversion of dry pond to wet pond	Conversion of an existing dry pond to a wet pond	Acres	Yes

Table 2 presents the land use change BMPs included in the Tool, with a definition, units treated and indication of whether a credit for the BMP has been approved by the CBP. For these BMPs, the pollutant removal effectiveness is calculated based on the difference in pollutant loads for the two land use types in question, as described in Section 4 of this manual.

Table 2. Land Use Change BMPs Included in the Clean Water Optimization Tool			
BMP	**Definition**	**Units Treated**	**Credit Approved by CBP?**
Forest buffers	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.	Acres of urban pervious land	Yes
Urban tree planting	Planting trees on urban pervious areas at a rate that would produce a forest-like condition over time.	Acres of urban pervious land	Yes
Impervious cover removal	Change in land use from impervious to pervious urban	Acres of impervious	Yes
Urban cover crop	Conversion of urban turf area to cover crop such as minimally managed warm season grass or hay that is not fertilized	Acres of urban pervious land	No
Soil augmentation	Use of deep tilling and soil amendments to increase soil porosity and reduce compaction, thereby reducing stormwater runoff from urban pervious lands.	Acres of urban pervious land	No

Table 3 presents the municipal programs and other practices included in the Tool, with a definition, units treated and indication of whether a credit for the BMP has been approved by the CBP. Appendix A of this manual describes how pollutant removal effectiveness was calculated for these practices. Note that although the credits for Living Shorelines and Stream Restoration have been approved by the CBP, the recommended protocols have not yet been fully incorporated into MAST. Urban Nutrient Management is not included in the Tool because the State of Maryland has indicated it will apply reductions for this BMP to all pervious lands in the state, which will ultimately reduce the target for individual counties. These reductions are not currently reflected in the Tool results. Elimination of Discovered Nutrient Discharges from Grey Infrastructure was not included in the Tool because none of the Eastern Shore communities would be eligible to take this credit.

Table 3. Municipal Programs and Practices Included in the Clean Water Optimization Tool

BMP	Definition	Units Treated	Credited by CBP?
Pet waste program	Municipal programs focused on reducing pet waste through enforcement, education and installation of pet waste pickup stations. Credit is based on pollutant reduction associated with installation of pet waste stations and assumes that 10 bags per stations per day are used.	Number of pet waste stations	No
Street sweeping	Regular pickup of street dirt using a street sweeper. Greater credit is given for streets swept 25 times per year versus a sporadic sweeping frequency. Reporting options include acres swept or pounds of material collected by the sweeper.	Impervious acres or pounds of material removed by sweeper	Yes
Outfall netting systems	Netting systems that are attached to stormwater outfalls to capture trash and organic material	Acres	No
User-defined BMP	This is an option to include any other BMP that is not currently included in the Tool. Users must enter pollutant removal efficiencies, % impervious cover in drainage area and BMP cost per acre treated. An example is the use of wood chip bioreactors to treat runoff from mixed urban/agricultural land.	Acres	No
Living shoreline	Protection of shoreline from excessive wave action by creating a marsh or an offshore structure such as a sill, breakwater or sand containment structure. For identified living shoreline projects, entering the width of vegetated area, average bank height and recession rate will result in better estimates.	Linear feet	Yes

Table 3. Municipal Programs and Practices Included in the Clean Water Optimization Tool

BMP	**Definition**	**Units Treated**	**Credited by CBP?**
Stream restoration	Stream restoration in urban areas is used to restore the urban stream ecosystem by restoring the natural hydrology and landscape of a stream, help improve habitat and water quality conditions in degraded streams. Users can enter detailed site information if known (see below) or can use the interim removal rate that is based simply on linear feet of stream restored. In addition to the linear feet of stream restored, users must enter the following inputs to receive credit for the following protocols described by Schueler and Stack (2014): 1. Prevented sediment: a. Stream erosion rate (ft/yr) b. Bank height (ft) 2. Nutrient processing: a. Stream width at median baseflow (ft) 3. Floodplain reconnection: a. Floodplain width (ft) b. Floodplain storage (ft^3) c. Watershed curve number d. Rain event to access floodplain (inches)	Linear feet	Yes

If you do NOT want to include certain BMPs in your scenario, enter a ZERO in the Maximum Practical Units Treated column or leave it blank. For example, you may wish to exclude BMPs that are not credited in MAST, BMPs that are not applicable in your county, or BMPs with very low community acceptance.

The maximum practical number of units that can be treated by each BMP is an important data input because it allows the Tool to optimize BMP scenarios based on what is actually possible, so the resulting suite of BMPs is realistic. This input can be estimated through desktop analysis or field assessments. Field assessments provide a more accurate depiction of how many units can practically be treated with each BMP but they require more time and effort. Some counties have already conducted field assessments of restoration potential, and can readily derive the number of units that can practically be treated, at least for certain BMPs. Another potential source of this information is existing plans and studies, such as watershed plans, stream assessments and other similar documents that identify specific locations to install BMPs.

While field assessments are necessary to identify specific sites for installing BMPs, a desktop analysis can provide a reasonable estimate of restoration potential for use in developing a planning-level BMP scenario using the Tool. A desktop analysis uses GIS data to calculate the total units available for treatment in the county (i.e., acres of pervious land, linear feet of stream) and discounts this number based on local assumptions that account for limitations on implementation feasibility (e.g., landowner willingness to install BMPs, site constraints).

There is no exact method for estimating the maximum practical number of units that can be treated by each BMP, but some basic guidance is provided in Table 4. The table presents a series of questions to guide an evaluation of treatment potential for each BMP, and provides some basic assumptions that can be used by counties who have little available data on the feasibility of BMP implementation. These assumptions can be used with the following local GIS layers to develop default conservative estimates that can later be refined as field assessments are completed:

- Land use
- Land cover (impervious, forest , other pervious)
- Hydrology
- Stormwater BMPs and storm sewer infrastructure
- Property info (public vs private)

Table 4. Estimating the Maximum Practical Units Treated by Each BMP

BMP	**General Guidance and Assumptions**
Conversion of dry pond to wet pond or wetland	• Identify the number of dry ponds in the jurisdiction (use GIS layer if available, or get a count from a BMP database) • Assume the ponds provide no effective water quality treatment • Estimate how many can be retrofitted (based on field assessments; if unknown, assume 50%) For ponds with retrofit potential, estimate impervious area treated (if unknown, assume average drainage area of 10 acres and 20% impervious)

Table 4. Estimating the Maximum Practical Units Treated by Each BMP

BMP	**General Guidance and Assumptions**
Stream restoration	• Estimate the number of stream miles in the jurisdiction that are in need of restoration (based on field assessments; if unknown, assume at least 25%) • Of these, determine what percentage are feasible for restoration in conjunction with upland retrofits (if unknown, assume 5% based on physical factors, land ownership, etc.) • Convert resulting estimate of stream miles to linear feet (assumes both banks will be restored) • Where specific stream restoration projects have been identified, the following information is required (in addition to linear feet of stream restored) to receive credit based on the three protocols described by Schueler and Stack (2014 (more than one protocol can be used for the same project): 1. Prevented sediment: a. Stream erosion rate (ft/yr) b. Bank height (ft) 2. Nutrient processing: a. Stream width at median baseflow (ft) 3. Floodplain reconnection: a. Floodplain width (ft) b. Floodplain storage (ft^3) c. Watershed curve number d. Rain event to access floodplain (inches)
Living shorelines	• Determine the total length of shoreline in the jurisdiction • Estimate the proportion that is suitable to install living shorelines (Maryland DNR's Coastal Atlas http://www.dnr.state.md.us/map_template/coastalmaps/coastal_atlas_shorelines.html can be used if analysis has been completed for your area and suitability has not been determined through local sources.) • Note: shoreline practices are not appropriate in areas with a slight recession rate (less than 2 feet of loss per year) • For identified living shoreline projects, entry of the following additional information will result in better estimates: 1. Width of vegetated area: an optional input that allows reduction estimates from sedimentation, denitrification and the "marsh Redfield Ratio" credit 2. Average bank height: if left blank, two feet will be used as a conservative estimate 3. Recession rate: use DNR's Coastal Atlas to determine average, if unknown. If left blank, two feet will be used as a conservative estimate.
Forest buffers	• Identify streams and shorelines with inadequate buffers (use GIS to summarize land cover data within 100 feet of waterbody) • Estimate the acreage potentially available for planting (e.g., all land classified as non-forest vegetation within the riparian zone) • Estimate the proportion that is feasible to reforest (use GIS to overlay with property and land use layers and assume 90% of public land is feasible and 15% of private land, or just assume 25% of all land is feasible for buffers.

Table 4. Estimating the Maximum Practical Units Treated by Each BMP

BMP	General Guidance and Assumptions
Urban tree planting, soil augmentation, urban cover crops	• Estimate the acres of turf in the jurisdiction (use GIS and land cover data or derive from MAST) • Break down this acreage by residential, public, and commercial/institutional (or use default values from Schueler and Lane 2013: 60-80% of turf is on residential land, 10-15% is on commercial/institutional land and 15-20% is owned by public agencies) • Of the turf on commercial/institutional land and public land, a portion of this land may provide an opportunity for urban tree planting, urban cover crops or soil augmentation. The user should decide how much can be used for each practice and what proportion may be used for stormwater retrofits, keeping in mind that landowner willingness to install BMPs will be an important consideration. • Turf on residential land may provide an opportunity for urban tree planting, urban cover crops or soil augmentation. The user should decide how much can be used for each practice and what proportion may be used for stormwater retrofits. Assume that the percentage of private land available for these BMPs is significantly lower than for public land.
Street Sweeping	• Three credits are available. For streets that are swept at least 25 times per year, credit can be based on the acres swept or the pounds of material removed, if tracked. For streets that are swept less frequently, only a credit for sediment is available. • If the jurisdiction currently has a street sweeping program, determine how many acres of street are swept, on what interval, and whether the material collected by the sweeper is weighed. • Evaluate the possibility of increasing the acres of streets swept, the frequency of sweeping (if less than 25 times/year) or weighing the material collected (if not already being done) • If the jurisdiction does not have a street sweeping program, evaluate the possibility of establishing one and estimate the potential acres that could be swept at least 25 times/year.
Outfall netting systems	• Determine the number of major outfalls in the jurisdiction (use GIS) • Estimate the percentage of outfalls where it is feasible to install outfall netting systems (if unknown, select all outfalls within 100 feet of a road)
Pet waste program	• If a program is already in place, determine the number of pet waste stations installed in the jurisdiction. *Note that this credit assumes that 10 bags are used per day at each station.* • If a pet waste program does not exist and/or pet waste stations have not been installed, identify strategic locations to install pet waste stations that are heavily used by dog owners, such as dog parks, public parks, near walking trails, outside pet stores and vets, etc.
Ditch enhancement	• Estimate the miles of road or tax ditches in the jurisdiction (use GIS) • In the absence of field data, assume 10% to 25% of these ditches could be converted to a bioswale or dry swale (use the lower end if water table is generally high - within 3 feet of the bottom of the ditch - in the jurisdiction) • Assume an average drainage area to each 100 foot bioswale is 0.1 acres and 42% impervious. These drainage area numbers assume only treatment of the adjacent road as well as water falling on the ditch itself.

Table 4. Estimating the Maximum Practical Units Treated by Each BMP

BMP	General Guidance and Assumptions
Stormwater retrofits, impervious cover removal	• Estimate the acres of impervious cover in the jurisdiction (use GIS and land cover data or derive from MAST) • Estimate the proportion of impervious cover that has inadequate or no stormwater treatment, and break out by public/institutional versus private ownership, or by location (i.e., rooftops versus road right-of-way, depending on BMPs of interest). • Assume that 15% of untreated impervious cover on public and institutional land is feasible for retrofitting • Assume that 15% of impervious cover on private land is feasible for retrofitting, but only 25% of this land has a willing landowner • Divide the estimated feasible acreage up across the various stormwater retrofit BMPs.

More detailed guidance on using desktop and field assessments to identify specific sites for BMP implementation is provided in the resources listed in Table 5.

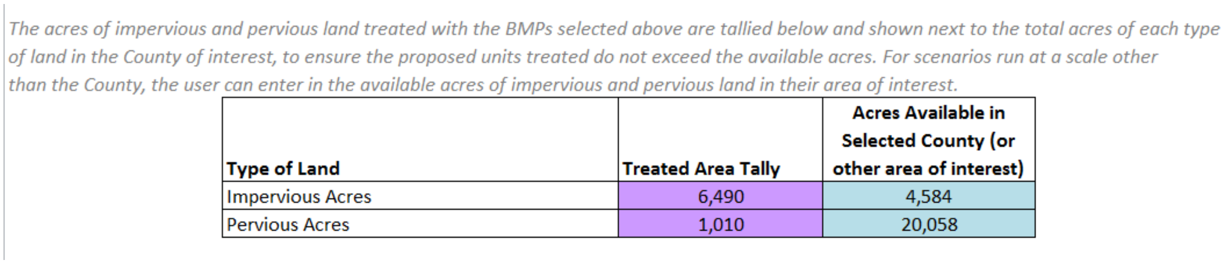
Table 5. Resources for Detailed Assessments of Potential for BMP Implementation

BMP	Resources
Stormwater retrofits	Urban Stormwater Retrofit Manual (Schueler et al 2007)
Impervious cover removal	
Stream restoration	Unified Stream Assessment (Kitchell and Schueler 2004)
Forest buffers	
Regenerative Stormwater Conveyance	
Urban tree planting	Urban Subwatershed and Site Reconnaissance (Wright et al 2005)
Urban nutrient management	
Downspout disconnection	
Street sweeping	
Pet waste programs	
Outfall netting systems	
Urban cover crops	
Soil augmentation	

After determining the maximum practical units treated for each BMP, the user should enter the percent impervious cover in the drainage area for each of the stormwater retrofit practices (exceptions include pavement BMPs, rooftop BMPs, and Stormwater Tree Pits/Structural Soils, which are all assumed to treat 100% impervious cover), Outfall Netting Systems and User-Defined BMP. Impervious cover percentages vary by practice type and level of urbanization but typical values are provided here: bioretention practices (15-95%), filtering and infiltration practices (30-100%), channels (35%), ponds and wetlands (25%) and outfall netting systems (15%).

Communities with a significant proportion of agricultural land also have the option to enter the percent of the BMP drainage area that includes agricultural land. This option is available for BMPs that treat relatively large drainage areas that typically include pervious cover, such as ponds, wetlands and swales. If the proposed BMP drainage area characteristics are unknown, the user can make an estimate based on the relative proportion of agricultural land in the more urbanized sections of the jurisdiction. The assumption here is that in the process of implementing stormwater BMPs to meet the required urban load reductions, it is likely that some BMPs will capture and treat runoff from adjacent agricultural land. This is particularly the case on the Eastern Shore which is still fairly rural in nature. There is currently no mechanism for counting these reductions towards the urban sector targets. The Tool allows the user to track these reductions separately so that opportunities to receive credit or trade with other sectors can be further explored.

Once the Maximum Practical Units Treated are entered, the acres of urban impervious and urban pervious land are tallied below the BMP table, along with the total acres of urban impervious and urban pervious land in the selected County (based on the 2010 MAST progress run). This comparison helps to ensure that the user does not exceed the available urban acres with the proposed units treated. If the available acres are exceeded, a warning appears in RED. For scenarios run at a scale other than the County, the user can manually enter in the acres of available imperious and pervious land.

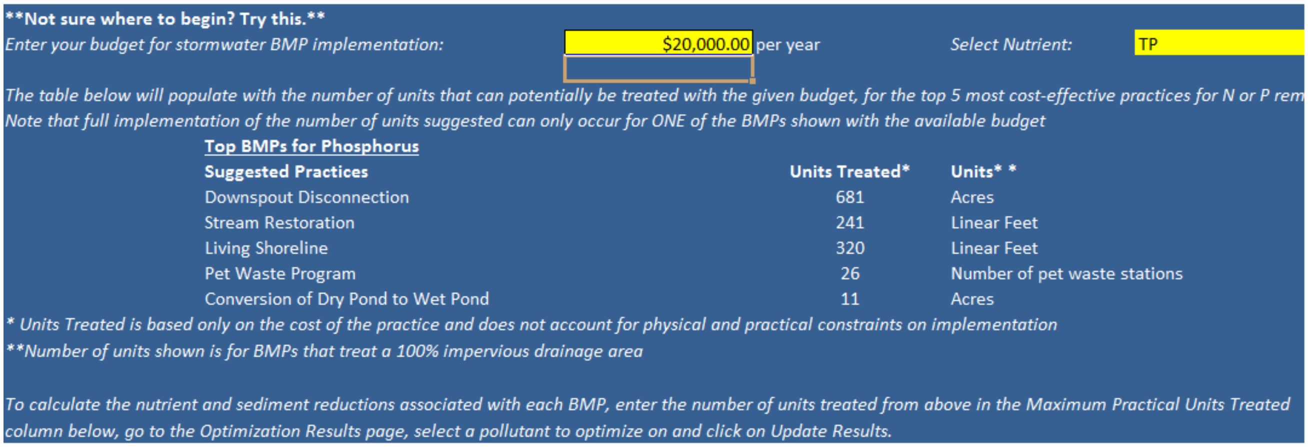


The acres of impervious and pervious land treated with the BMPs selected above are tallied below and shown next to the total acres of each type of land in the County of interest, to ensure the proposed units treated do not exceed the available acres. For scenarios run at a scale other than the County, the user can enter in the available acres of impervious and pervious land in their area of interest.

Type of Land	Treated Area Tally	Acres Available in Selected County (or other area of interest)
Impervious Acres	6,490	4,584
Pervious Acres	1,010	20,058

Figure 3. Treated Area Tally

An option in the Scenario Setup page is to enter the community's annual budget for implementation of stormwater practices, and select either TN or TP. The results table in this section will populate with the number of units that could potentially be treated with this amount of money (based on price per pound of removal alone as opposed to the number of available units) for each of the top four most cost-effective practices for nitrogen removal or phosphorus removal. The user can then enter the number of units treated as the Maximum Practical Units Treated for those BMPs and view the Optimization Results to compare the nutrient and sediment reductions associated with each BMP. This option is useful for those communities who have very limited information on the extent to which they can install stormwater BMPs in their community and/or have very limited budgetary resources. The results can help them to target a smaller number of BMPs on which to focus their efforts for quantifying maximum practical units treated, and allows the user to compare these BMPs in terms of how many units can be treated and pollutant reduced with a given budget.



****Not sure where to begin? Try this.****

Enter your budget for stormwater BMP implementation: $20,000.00 per year *Select Nutrient:* TP

The table below will populate with the number of units that can potentially be treated with the given budget, for the top 5 most cost-effective practices for N or P rem

Note that full implementation of the number of units suggested can only occur for ONE of the BMPs shown with the available budget

Top BMPs for Phosphorus

Suggested Practices	**Units Treated***	**Units* ***
Downspout Disconnection	681	Acres
Stream Restoration	241	Linear Feet
Living Shoreline	320	Linear Feet
Pet Waste Program	26	Number of pet waste stations
Conversion of Dry Pond to Wet Pond	11	Acres

** Units Treated is based only on the cost of the practice and does not account for physical and practical constraints on implementation*

***Number of units shown is for BMPs that treat a 100% impervious drainage area*

To calculate the nutrient and sediment reductions associated with each BMP, enter the number of units treated from above in the Maximum Practical Units Treated column below, go to the Optimization Results page, select a pollutant to optimize on and click on Update Results.

Figure 4. Optional Tool section that displays the units of the most cost-effective that could be treated with a given budget

Optionally, the user can select a priority BMP to receive a higher weight in the optimization process. The user should select the desired BMP from the dropdown list provided. This feature allows the user to create optimization scenarios that also account for factors such a community support or available funding for a certain type of BMP. Another example of when this feature might be useful is to prioritize BMPs that are good at removing another local pollutant of concern (e.g., pet waste programs when there is a local bacteria impairment).

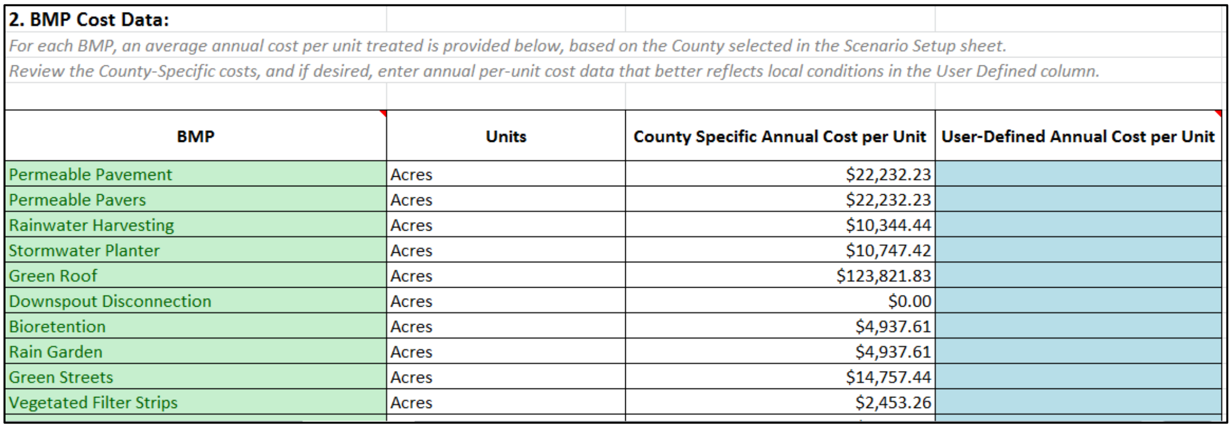
3.2. Step 3: BMP Costs

This sheet displays the BMP costs used in the Tool, all of which can be replaced with data that better represent local BMP costs. For each BMP, costs are presented as an average annual cost per unit treated. This includes design, construction, land, annual routine maintenance, intermittent maintenance and county costs related to inspection and enforcement. Sources and assumptions associated with the cost data are provided in Appendix A.

In addition to the annual cost per unit for each BMP, users can also modify the defaults values for the following variables used to develop the annualized costs:

- Land cost per developable acre (default is $100,000)
- Percent of land that is developable (default is 50%)
- Interest rate associated with bond payment required to finance initial BMP construction (default is 3% over the life cycle of the project)
- Number of years over which to project costs (default is 20 years, which is the typical lifespan of most BMPs included in the Tool)

In the BMP cost table, the County-Specific Annual Cost Per Unit column will automatically populated based on the count of interest selected in the Scenario Setup worksheet. Users should review these costs and, if preferred, override them by entering better local estimates in the User-Defined Annual Cost Per Unit column for BMPs. The BMP costs used in the Tool are considered planning level costs and are not suitable for assessing costs in specific situations because actual BMP costs are very site-specific and can vary significantly by location, land use and landscape characteristics, project scale, design features, zoning and permitting conditions and land values.



2. BMP Cost Data:

For each BMP, an average annual cost per unit treated is provided below, based on the County selected in the Scenario Setup sheet.

Review the County-Specific costs, and if desired, enter annual per-unit cost data that better reflects local conditions in the User Defined column.

BMP	Units	County Specific Annual Cost per Unit	User-Defined Annual Cost per Unit
Permeable Pavement	Acres	$22,232.23	
Permeable Pavers	Acres	$22,232.23	
Rainwater Harvesting	Acres	$10,344.44	
Stormwater Planter	Acres	$10,747.42	
Green Roof	Acres	$123,821.83	
Downspout Disconnection	Acres	$0.00	
Bioretention	Acres	$4,937.61	
Rain Garden	Acres	$4,937.61	
Green Streets	Acres	$14,757.44	
Vegetated Filter Strips	Acres	$2,453.26	

Figure 5. BMP Cost Data entry sheet

3.3. Step 4: Optimization Results

In this worksheet, the first step is to enter the nutrient and sediment reductions from stormwater retrofits installed between 2013 and the present and from BMPs that are "in the pipeline" for construction. This is an optional step for communities that have already compiled this information and/or are moving forward on implementation. The reductions from installed/planned BMPs are used in the Tool to update the nutrient and sediment reduction targets for which the BMP scenarios are being developed.

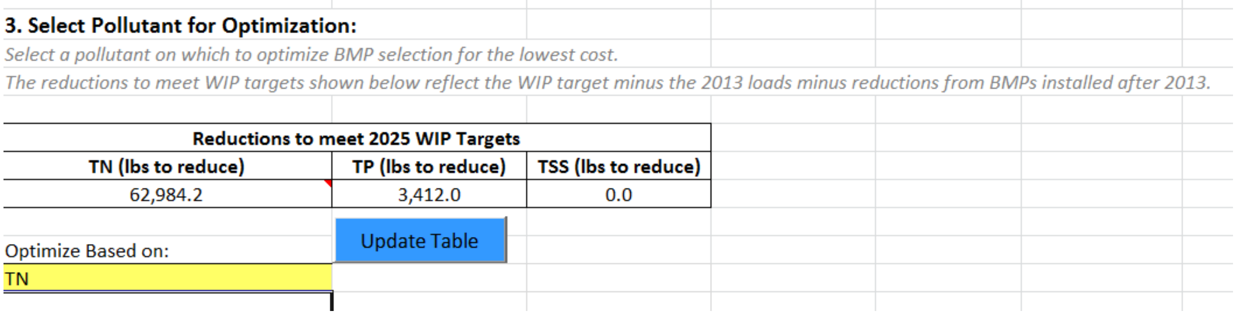
The next step, also optional, is to enter the required information to use trading as an option to help meet the required pollutant reductions. Although the details of how a trading program would work are still being worked out (http://www.mdnutrienttrading.com/; General Assembly of Maryland Article-Agriculture, Section 8-901 to 8-904), trading offers the opportunity to achieve the same or better water quality improvements at a lower cost. On the Eastern Shore of Maryland, the cost to install stormwater practices is significantly greater per pound of pollutant removed compared to other sectors such as agriculture and septic systems. Cross-sector trading is provided as an option in the Tool so that communities can explore how it could possibly affect their bottom line. The major inputs in this section are:

1) willingness to pay: the maximum price ($/lb) you are willing to pay to purchase a credit from the agricultural and/or septic sector ("currency" options include pounds of TN and TP)

2) maximum amount to spend: this entry provides an upper limit to the amount of your budget you will allocate to trading

Estimated costs of purchasing nitrogen credits from the agricultural sector range from less than $3/lb up to $50/lb (Jones et al. 2010; STAC, 2013; Van Houtven et al. 2012; Legislative Budget and Finance Committee 2013). Note that the pollutant reductions achieved through trading are limited in the Tool to 10% of total required reductions.

Next, the user must select a pollutant on which to optimize their BMP scenario. The options include TN, TP, TSS and TN & TP. Most commonly, a community will elect to optimize for the pollutant that requires the greatest reduction (relative to the current load). Optimization means that BMPs are selected in priority order based on their cost-effectiveness in removing the pollutant(s) of concern. If a priority BMP was identified in the Scenario Setup worksheet, this is factored into the optimization process as well. If TN & TP is selected for optimization, a box showing the relative weight of each pollutant in the optimization routine will appear. The default weighting is 50% for TN and 50% for TP, but this can be changed if desired by entering a different weight in the "Nitrogen Weight" box (the TP weight will update automatically). Once you select the pollutant of interest, you can click on the "Update Table" button to refresh the results table for your scenario.



3. Select Pollutant for Optimization:

Select a pollutant on which to optimize BMP selection for the lowest cost.

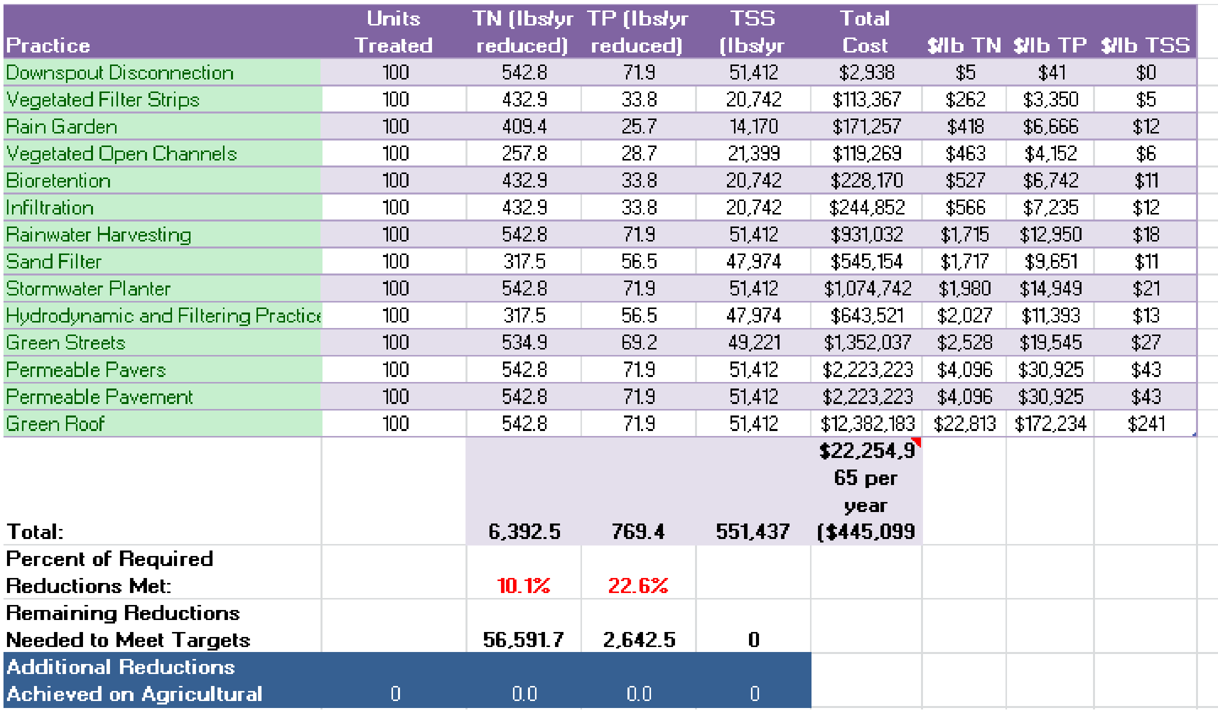
The reductions to meet WIP targets shown below reflect the WIP target minus the 2013 loads minus reductions from BMPs installed after 2013.

Reductions to meet 2025 WIP Targets		
TN (lbs to reduce)	TP (lbs to reduce)	TSS (lbs to reduce)
62,984.2	3,412.0	0.0

Optimize Based on:
TN

Figure 6. Selecting a pollutant for optimization

Figure 7 shows some sample results from the Tool. The results table lists each BMP included in the scenario (listed in order of cost-effectiveness for the selected pollutant of interest), the number of units treated, pollutants reduced and cost. At the bottom of the table are the total annual pollutant load reductions, the total annual cost and the total cost for the scenario. The percent of required load reductions that were met by the scenario, as well as any reductions remaining are also provided.



Practice	Units Treated	TN (lbs/yr reduced)	TP (lbs/yr reduced)	TSS (lbs/yr	Total Cost	$/lb TN	$/lb TP	$/lb TSS
Downspout Disconnection	100	542.8	71.9	51,412	$2,938	$5	$41	$0
Vegetated Filter Strips	100	432.9	33.8	20,742	$113,367	$262	$3,350	$5
Rain Garden	100	409.4	25.7	14,170	$171,257	$418	$6,666	$12
Vegetated Open Channels	100	257.8	28.7	21,399	$119,269	$463	$4,152	$6
Bioretention	100	432.9	33.8	20,742	$228,170	$527	$6,742	$11
Infiltration	100	432.9	33.8	20,742	$244,852	$566	$7,235	$12
Rainwater Harvesting	100	542.8	71.9	51,412	$931,032	$1,715	$12,950	$18
Sand Filter	100	317.5	56.5	47,974	$545,154	$1,717	$9,651	$11
Stormwater Planter	100	542.8	71.9	51,412	$1,074,742	$1,980	$14,949	$21
Hydrodynamic and Filtering Practice	100	317.5	56.5	47,974	$643,521	$2,027	$11,393	$13
Green Streets	100	534.9	69.2	49,221	$1,352,037	$2,528	$19,545	$27
Permeable Pavers	100	542.8	71.9	51,412	$2,223,223	$4,096	$30,925	$43
Permeable Pavement	100	542.8	71.9	51,412	$2,223,223	$4,096	$30,925	$43
Green Roof	100	542.8	71.9	51,412	$12,382,183	$22,813	$172,234	$241
Total:		**6,392.5**	**769.4**	**551,437**	**$22,254,965 per year ($445,099**			
Percent of Required Reductions Met:		10.1%	22.6%					
Remaining Reductions Needed to Meet Targets		**56,591.7**	**2,642.5**	**0**				
Additional Reductions Achieved on Agricultural	0	0.0	0.0	0				

Figure 7. Results Table

If you entered data for BMPs whose drainage areas include some agricultural land, the pollutant reductions achieved from these non-urban acres are not included in the reductions in the results table since there is currently no mechanism for the urban sector to get credit for reducing pollutants on agricultural land. Reductions from the agricultural sector are tallied separately below the total for informational purposes. Note that the costs to construct BMPs that treat agricultural land are included in the total scenario cost and will be more expensive per pound of pollutant reduced since the agricultural portion of the pollution is not included in the calculation.

If the optimized BMP scenario does not meet the pollutant reduction targets, the user can then go back and re-evaluate whether (and how) it is possible to increase the maximum practical number of units treated for highly cost-effective BMPs. For example, a county might use the Tool results to decide that they will aggressively pursue expansion of their street sweeping program by allocating additional resources towards purchase of sweepers with the goal of greatly increasing the number of acres that can practically be swept and reducing the total cost to achieve the pollutant reduction goals.

3.4. Results Charts

Results charts are provided on a four separate worksheets so they can be easily printed. These include a breakdown of the TN, TP and TSS reductions achieved by each BMP, as well as a breakdown of the portion of the total scenario cost associated with each BMP.

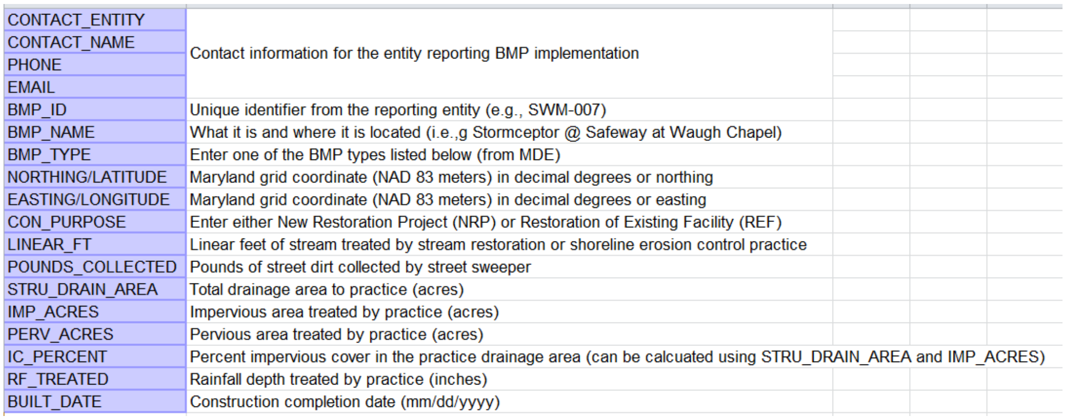
4. Using the Tool for Implementation Tracking

The Clean Water Optimization Tool was developed for local governments to create BMP scenarios to meet water quality goals and was not originally intended to be used for tracking or reporting purposes. However, based on the strong need for an implementation tracking tool, instructions are provided below on using the Tool for tracking progress.

Maryland communities must report any BMPs implemented to the Maryland Department of the Environment (MDE), who in turn will submit these BMPs to the Chesapeake Bay Program to report on implementation progress toward Chesapeake Bay restoration goals. Regulated NPDES MS4 communities report their progress on BMP implementation via existing MS4 permit reporting procedures. For unregulated communities, such as those on the Eastern Shore, MDE has developed a simple stormwater BMP reporting tool that is available here.

However, MDE's reporting tool and process does not provide local jurisdictions with any information on the nutrient and sediment reductions associated with the implemented practices. One option for communities to gage their progress is to enter the constructed projects into MAST. There are two problems with this approach. First, because MAST may not include newly approved protocols by the CBP (e.g., Stormwater Retrofit Expert Panel protocol for crediting retrofit projects, Stream Restoration Expert Panel for crediting stream restoration) the reductions calculated in MAST will not reflect the "approved" and science-backed reductions. Second, MAST does not provide a comparison of a community's progress to their pollutant load reduction goals.

To help communities track their implementation progress while facilitating reporting to MDE, the Tool can be used with a spreadsheet provided on the Tool download website. The spreadsheet can be used to record important information about each BMP implemented in the jurisdiction and can be provided on an annual basis to local agencies, non-profits, universities and other groups involved in BMP implementation to request the necessary information about their progress in the previous year. Once complete, the information can be submitted to MDE using their reporting tool.



CONTACT_ENTITY	Contact information for the entity reporting BMP implementation
CONTACT_NAME	
PHONE	
EMAIL	
BMP_ID	Unique identifier from the reporting entity (e.g., SWM-007)
BMP_NAME	What it is and where it is located (i.e.,g Stormceptor @ Safeway at Waugh Chapel)
BMP_TYPE	Enter one of the BMP types listed below (from MDE)
NORTHING/LATITUDE	Maryland grid coordinate (NAD 83 meters) in decimal degrees or northing
EASTING/LONGITUDE	Maryland grid coordinate (NAD 83 meters) in decimal degrees or easting
CON_PURPOSE	Enter either New Restoration Project (NRP) or Restoration of Existing Facility (REF)
LINEAR_FT	Linear feet of stream treated by stream restoration or shoreline erosion control practice
POUNDS_COLLECTED	Pounds of street dirt collected by street sweeper
STRU_DRAIN_AREA	Total drainage area to practice (acres)
IMP_ACRES	Impervious area treated by practice (acres)
PERV_ACRES	Pervious area treated by practice (acres)
IC_PERCENT	Percent impervious cover in the practice drainage area (can be calcuated using STRU_DRAIN_AREA and IMP_ACRES)
RF_TREATED	Rainfall depth treated by practice (inches)
BUILT_DATE	Construction completion date (mm/dd/yyyy)

Figure 8. Fields provided in the BMP tracking spreadsheet

To track progress towards the TMDL targets, a community can tally up the units treated for each BMP using the spreadsheet on an annual basis and enter these units treated in a new Tool scenario. This will provide an estimate of the associated pollutant reductions and progress towards the TMDL targets[1].

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[1] One caveat is that stormwater retrofit projects that treat anything other than 1" of rainfall will have a different credit than what is shown in the Tool because the default assumption for retrofits in the Tool is that they are designed to treat 1".

Appendix A. Documentation

Assumptions and data sources used to develop the Tool are documented below for BMP costs, pollutant removal and optimization.

A.1 Cost Data

The primary source of cost data was King and Hagan (2011), a study commissioned by MDE to assist Maryland communities with developing cost estimates for their urban BMP scenarios using MAST. The cost-estimating framework used develops annualized life-cycle cost estimates based on the annual bond payment required to finance the initial cost of the BMP (including design, construction and land costs; assumes a 20-year bond at 3% interest) plus average annual routine and intermittent maintenance costs. For all BMPs that require land it was assumed that: 1) the opportunity cost of developable land is $100,000 per acre and 2) 50% of projects that require land take place on developable land with the rest taking place on land that is not developable (e.g., stream valleys, public parks). This brings the opportunity cost of land for BMPs to $50,000 per acre. The 20 year timeframe for bond payment, 3% interest rate, opportunity cost of developable land and % of land that is developable are all variables that can be modified in the Tool if desired. The cost adjustment factors provided by King and Hagan (2011) for Maryland counties are used in the Tool.

Because the King and Hagan (2011) values were reported in dollars per impervious acre, the scenario costs for BMPs that treat both impervious and pervious land were calculated as follows. For the impervious portion of the drainage area, the King and Hagan values were applied directly, but for the pervious portion the King and Hagan values were applied to the “equivalent” impervious acres, meaning the amount of impervious cover that would generate an equivalent amount of runoff as the pervious portion. The equivalent imperviousness was calculated as:

$$Equivalent\ Impervious = \frac{V_I + V_P + V_A}{0.95 * \frac{WQ_V}{12} * 43560}$$

where WQ_V is the water quality volume and is equal to 1 inch, 12 is a conversion from inches to feet, 0.95 is the runoff coefficient of impervious cover, 43,560 is a conversion from square feet to acres, and V_I, V_P, and V_A are the runoff volume associated with the impervious, urban pervious, and agricultural portion of the drainage area, respectively. They are calculated in the following way:

$$V_I = \frac{MPU * \%IC * WQ_V * 0.95 * 43560}{12}$$

$$V_A = \frac{MPU * \%AG * WQ_V * 0.40 * 43560}{12}$$

$$V_P = \frac{MPU * \left(1 - (\%IC + \%AG)\right) * WQ_V * 0.22 * 43560}{12}$$

where MPU is the maximum practical units treated, $\%IC$ is the percent impervious cover, WQ_V, 12, and 43560 are as defined above, $\%AG$ is the percent of agricultural cover, and 0.95, 0.40, and 0.22 are the runoff coefficients for impervious, agriculture, and pervious, respectively. The runoff coefficients used above were used in place of the standard MDE method of calculating runoff coefficient for a site ($Runoff\ Coefficient = 0.05 + 0.009 * \%IC$) because of the potential addition of agricultural land use.

Table A1 lists the source of cost data for each BMP included in the Tool and notes where any additional modifications were made.

Table A1. Sources of Cost Data in the Clean Water Optimization Tool

BMP	Source of Cost Data and Assumptions/Modifications
Permeable pavement	King and Hagan (2011), averaged the costs for permeable pavement w/o sand and permeable pavement w/ sand
Permeable pavers	King and Hagan (2011), averaged the costs for permeable pavement w/o sand and permeable pavement w/ sand
Rainwater harvesting	Schueler et al (2007), used unit cost for rain barrels, which was higher than cost for cisterns. Converted $/cf to $/impervious acre using conversion factor of 3,630. Assumed pre-construction would be ~5% of construction and land costs zero. Assumed annual and intermittent maintenance costs to be ~1% of construction.
Stormwater planter	Schueler et al (2007), Converted $/cf treated to $/impervious acre using conversion factor of 3,630. Assumed pre-construction would be ~20% of construction and land costs zero. Assumed routine and intermittent maintenance costs to be ~1% of construction.
Green roof	Schueler et al (2007), Converted $/cf treated for extensive green roofs to $/imp ac using conversion factor of 3630. Assumed pre-construction would be ~40% of construction and land costs zero. Assumed annual and intermittent maintenance costs to be ~ 2% of construction.
Downspout disconnection	Schueler et al (2007), the median cost per cubic foot from was converted to a cost per impervious acre based on these assumptions: each rooftop treated is 1,500 ft^2 and the first 1 inch of rainfall is treated by this practice. Assumed land and maintenance costs are zero.
Bioretention	King and Hagan (2011), used cost for bioretention (new/suburban)
Rain garden	King and Hagan (2011), used cost for bioretention (new/suburban)
Green streets	King and Hagan (2011), used cost for bioretention (retrofit/ultra-urban) but assumed land costs were zero because of location of practice within right-of-way.

Table A1. Sources of Cost Data in the Clean Water Optimization Tool

BMP	**Source of Cost Data and Assumptions/Modifications**
Vegetated filter strips	Schueler et al (2007), Converted $/cf to $/impervious acre using conversion factor of 3,630. Assumed pre-construction would be ~10% of construction. Assumed annual and intermittent maintenance costs to be ~1% of construction. Assumed land required would be similar to bioswales/vegetated open channels.
Hydrodynamic structures and filtering practices	King and Hagan (2011), hydrodynamic structures
Infiltration practices	King and Hagan (2011), averaged cost of infiltration practices w/ and w/o sand
Tree pits/structural soils	Schueler et al (2007), Converted $/cf to $/impervious acre using conversion factor of 3,630. Assumed pre-construction would be ~20% of construction and land costs zero because of location within right-of-way. Assumed annual and intermittent maintenance costs to be ~1% of construction.
Sand filter	King and Hagan (2011), averaged cost of above- and below-ground filtering practices
Dry swale/bioswale	King and Hagan (2011), bioswale
Wet swale	King and Hagan (2011), assumed costs were comparable to vegetated open channels
Vegetated open channels	King and Hagan (2011)
Regenerative Stormwater Conveyance	Based on average estimated construction cost per impervious acre for two Wicomico County projects. Assumed that land requirements were similar to bioswale.
Wet ponds	King and Hagan (2011), wet ponds and wetlands (new)
Constructed wetlands	King and Hagan (2011), wet ponds and wetlands (new)
Extended detention ponds	King and Hagan (2011), dry ED ponds (new)
Ditch enhancement	King and Hagan (2011), assumed the cost would be similar to a bioswale but land costs are zero because of location with right-of-way/drainage channel.
Conversion of dry pond to wet pond	The median value for construction cost per impervious acre treated from Schueler et al (2007) was used and was converted to a cost per acre treated. It was assumed that design costs for pond retrofits would be similar to the design cost associated with installing a new wet pond or wetland as a retrofit, so the value of 50% from King and Hagan (2011) was used. The operation and maintenance and county implementation cost assumptions provided by King and Hagan (2011) for wet ponds and wetlands were assumed to be applicable to pond retrofits. Land values were set at zero since the BMP involves modification to an already-constructed practice for which land has already been acquired.
Forest buffers	King and Hagan (2011), but converted costs from $/impervious acre to $/pervious acre treated
Urban tree planting	King and Hagan (2011), but converted costs from $/impervious acre to $/pervious acre treated
Impervious cover removal	King and Hagan (2011), impervious urban surface reduction
Urban cover crop	Modified estimates from Duffy (2008) and assumed the major annual cost would be for planting, harvesting and hauling. The resulting value was doubled to account for the fact that this

Table A1. Sources of Cost Data in the Clean Water Optimization Tool

BMP	Source of Cost Data and Assumptions/Modifications
	practice would be applied on small parcels and would not realize economies of scale. Also used value from Main Street Economics (2012) for comparison and used same assumptions regarding land costs as for urban tree planting from King and Hagan (2011).
Soil augmentation	Schueler et al (2007), Converted $/cf to $/impervious acre using conversion factor of 3630. Assumed pre-construction would be ~10% of construction. Assumed annual and intermittent maintenance costs to be ~1% of construction. Used same assumptions regarding land costs as for urban tree planting from King and Hagan (2011).
Pet waste program	See description below table.
Street sweeping	King and Hagan (2011)
Outfall netting systems	Stack et al (2013), assumed pre-construction would be ~20% of construction. Assumed annual and intermittent maintenance costs to be ~10% of construction and land costs to be zero.
Living shoreline	Assumed $300/linear foot construction cost based on median of 10 linear shoreline projects (rounded up to account for inflation) funded by the Chesapeake Bay Trust on the Eastern Shore of Maryland. Assumed design costs are 20% of construction costs land costs are zero and maintenance requirements are the same as for stream restoration.
Stream restoration	King and Hagan (2011), but converted costs from $/impervious acre to $/linear foot treated

All construction costs were brought up to 2014 dollars using the Bureau of Labor Statistics inflation calculator http://data.bls.gov/cgi-bin/cipcalc.pl.

Very limited data was available to estimate the cost and pollutant removal effectiveness of programs to reduce pollution from pet waste, due to the variable nature of such programs as well as the difficulty in quantifying the effectiveness of outreach programs. For the purposes of the Tool, costs and pollutant removal were estimated for just one component of pet waste programs: installation of pet waste stations complete with signs, basket and bags for picking up pet waste in parks and public places.

In order to determine the total annual cost of the program, assumptions were made about the number of pet waste stations installed and the number of bag refills needed per year. Most of these assumptions were taken from the *Bacterial Implementation Plan for the James River and Tributaries- City of Richmond* (Maptech, 2011) for a typical program in Virginia. For example, it was assumed that 10 bags per day would be used at each pet waste station location. These same assumptions were used when estimating the pollutant reduction associated with pet waste programs so that program costs and reductions were estimated for the same number of pet waste bags.

The program components included in the “construction” cost are installation of pet waste stations with a sign and basket plus bag refills for the first year. Unit costs for the stations and bag refills were taken from Maptech (2011). Annual maintenance costs were assumed to include bag refills, the labor to replace bags and empty trashcans (15 minutes per station each week of staff time @ $25/hr), and trash disposal fees. For trash disposal, we assumed 10 bags a day collected per station * 0.1 lbs of waste per bag * 365/year to get the total lbs of waste collected per station per year. A typical cost of $0.05 per pound was used for trash disposal. Intermittent maintenance included replacement of two pet waste stations (due to vandalism or other damage). Annual county implementation costs were extrapolated from the county implementation costs estimated by King and Hagan (2011) and assumed to be minimal.

A.2 Pollutant Removal

Pollutant removal for stormwater retrofits included in the Tool were calculated based on the recommendations of the CBP Expert Panel on Stormwater Retrofits (Schueler and Lane 2012). The panel classified retrofits into two broad project categories -- new retrofit facilities and retrofits of existing BMPs. Given the diversity of possible retrofit applications, the panel decided that assigning a single universal removal rate was not practical or scientifically defensible. Every retrofit is unique, depending on the drainage area it treats, the treatment mechanism employed, its volume or size and the antecedent degree of stormwater treatment, if any. Instead, the panel elected to develop a protocol whereby the removal rate for each individual retrofit project is determined based on the amount of runoff it treats and the degree of runoff reduction it provides. The panel conducted an extensive review of recent BMP performance research and developed a series of retrofit removal adjustor curves to define sediment, nitrogen and phosphorus removal rates. Removal rates for new retrofits are derived from the adjuster curves based on the runoff depth captured by the practice and whether the BMP is defined as a “runoff reduction” or “stormwater treatment” practice (see Table A2).

For all the new stormwater retrofits include in the Tool, it was assumed that these BMPs were sized to treat/capture the 1” storm, which equates to TN, TP, and TSS reductions of approximately 60%, 70%, and 75%, respectively for runoff reduction (RR) practices and 35%, 55%, and 70% for stormwater treatment (ST) practices. Pollutant reduction efficiencies used for Extended Detention Ponds were 20%, 20% and 60% for TN, TP, and TSS respectively (Schueler and Lane, 2012). It was assumed that there is no interaction between BMPs (i.e., load reductions are all additive).

Table A2. Assumptions Regarding Stormwater Retrofits in the Clean Water Optimization Tool

BMP	**Type of Practice**	**Impervious % in Drainage Area**
Permeable pavement	RR	100%
Permeable pavers	RR	100%
Rainwater harvesting	RR	100%
Stormwater planter	RR	100%
Green roof	RR	100%
Downspout disconnection	RR	100%
Bioretention	RR	User-defined
Rain garden	RR	User-defined
Green streets	RR	User-defined
Vegetated filter strips	RR	User-defined
Hydrodynamic structures and filtering practices	ST	User-defined
Infiltration practices	RR	User-defined
Tree pits/structural soils	ST	100%
Sand filter	ST	User-defined
Dry swale	RR	User-defined
Wet swale	ST	User-defined
Vegetated open channels	ST	User-defined
Bioswales and Regenerative Stormwater Conveyance	RR	User-defined
Wet ponds	ST	User-defined
Constructed wetlands	ST	User-defined
Ditch enhancement	RR	User-defined

Conversion of a dry detention pond to a wet pond is one of the most likely BMP conversion scenarios. We assumed for this example that the detention pond was designed solely for flood and peak outflow rate control purposes and provided no water quality benefit. Based on the recommendations in Schueler and Lane (2012), it was assumed that the removal rate associated with the existing BMP was a 5% TN reduction and a 10% TP and TSS reduction, which left the removal rates associated with the converted BMP at 30% for TN, 45% for TP and 60% for TSS.

For land use change BMPs, nutrient and sediment removal performance is estimated based on the difference in pollutant loading for the two land use types in question. Land use/pollutant loading rates downloaded on January 22, 2014 from the MAST version deployed on December 15, 2013 are used in the Tool for the Eastern Shore counties to calculate the reductions from these BMPs. These land uses and loads are from the 2010 status scenario run. The corresponding land use changes for each BMP are:

- Forest buffers: urban pervious to forest, plus an efficiency applied to adjacent urban pervious acreage treated by the buffer (25% TN, 50% TP and 50% TSS based on CBP methods as described in August 2014 version of MAST documentation)

- Urban tree planting: urban pervious to forest
- Impervious cover removal: urban impervious to urban pervious
- Urban cover crop: urban pervious to hay without nutrients (note: in some counties the sediment load from hay without nutrients is greater than the load from urban pervious; in these cases, the sediment reduction from this BMP is assumed to be zero)
- Soil augmentation: runoff reduction associated with changing the curve number from 80 to 70 using a 2.6 inch rain event coupled with the retrofit removal adjustor curves for RR (Schueler and Lane 2012)

Table A3 notes the source of pollutant removal effectiveness data/assumptions for municipal programs and other practices. Note that although the credits for Living Shorelines and Stream Restoration have been approved by the CBP, the recommended protocols have not yet been fully incorporated into MAST. Our Tool allows the user to get credit for stream restoration using either the recently approved protocols (Schueler and Stack 2014), which require site-specific information, or the interim approved rate that is included in MAST.

Table A3. Sources of Performance Data in the Clean Water Optimization Tool

BMP	**Sources/Assumptions**
Pet waste program	See notes below table
Street sweeping	CBP MAST documentation (August 2014)
Outfall netting systems	Stack et al (2013)
Living shoreline	Drescher and Stack (2014)
Stream restoration	Schueler and Stack (2014); Bulk density of soil is assumed to be 1 g.cm^3 (62.4 lbs/ft^3)

Limited data is available on the pollutant removal performance of pet waste programs. Therefore, a number of assumptions were used to develop initial estimates of performance for these programs, which are not currently credited by the CBP. These estimates should be treated with caution.

Specific pollutant reductions were calculated for installation of pet waste stations complete with signs, basket and bags for picking up pet waste in parks and public places. To calculate reductions, it was assumed that a certain nutrient load was captured and properly disposed of on an annual basis in pet waste bags located in public places such as parks. The following formula was used:

*# of bags/yr * waste production (lbs/dog/day) * concentration of pollutant in dog waste (lb/lb) * fraction of daily waste captured per bag * fraction of pollutant delivered to stream * fraction of bags used to properly dispose of pet waste * 365 days/yr * fraction of dog walkers who rarely clean up after their dogs*

The values for waste production, concentration of pollutant in dog waste, and fraction of pollutant delivered to the stream were derived from the Watershed Treatment Model (Caraco, 2001), which calculates pollutant loads and reductions at the watershed scale. We assumed that for each station, 10 bags would be used each day, based on assumptions in the *Bacterial Implementation Plan for the James River and Tributaries- City of Richmond* (Maptech, 2011). We assumed that only some portion of bags taken from the pet waste stations would actually be used to properly dispose of pet waste, while some (25%) were either not used or were not properly disposed of. We also assumed that each bag would be taken by a dog owner and would capture approximately 1/3 of their dog's daily waste. Finally, we assumed that some portion of the bag users would have brought their own bag and properly disposed of the waste anyway, so the pollutant load reduction estimate was discounted based on data from Swann (1999) regarding the proportion of dog owners who typically do not clean up after their dogs. The resulting value is considered to be somewhat conservative.

A.3 Optimization

The optimization routine uses calculated $/lb reduction for TN, TP, or TSS, and puts selected BMPs in order of least expensive to most expensive (if a Priority BMP is selected, that BMP is bumped to the top in the ranking). Maximum practical units treated are fully implemented for the least expensive practices until goals have been met. If goals are met with fewer than the entered maximum practical units, only as many units as are needed to meet the goal are used.

A.4 Sources

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