The Green Values® Stormwater Management Calculator Methods

The Green Values® Stormwater Management Calculator allows a user to examine the opportunities to address urban flooding by implementing green infrastructure. The user defines a site then sets a goal of how much volume of rain will be captured or retained by adding green infrastructure improvements (best management practices or BMPs) to the area, then BMPs are added to the area and the tool presents feedback on the cost of construction and maintenance, in addition to estimating what percentage of the desired goal of volume retention is being met. Additionally, co-benefits, including cost reductions and real estate value, of these BMPs are calculated and presented to the user.

Site Information

The goal of the site definition is to establish the amount of land that is impervious including rooftops and paved areas, as well as tracking the type of landscaping on the site. There are several templates the user can implement and adjust, such as urban home, apartment building, suburban, etc. or the user can design their own custom location. There is also the ability to add several sites at once with the ability to customize each to allow the user to examine the result of a multisite program.

Green Improvements

Rainfall Data

To calculate the amount of runoff on the site requires knowledge of the amount of rainfall expected on the site. Therefore, the user is asked to enter a location of the scenario (City, Zip Code or County). This location is used to query the rainfall data obtained from The National Oceanic and Atmospheric Administration (NOAA)[1]. Data from this location gives the average rainfall and the distribution of daily rain for that area – using the weather stations that are within the extent of that location's borders (when there are no stations found, the extent is expanded until one or more stations are found). The information on the average and standard deviation of this location's daily rainfall is then used to synthesize the typical annual rainfall distribution assuming a log-normal distribution typical for daily rainfall. This synthesized average daily rainfall distribution is then used to calculate effective runoff for the scenario's site, with and without the added BMPs, for an entire year and for a storm for this location. Initially the location is set to be an average location in the US and can be changed by using the edit button to the left of the "Rainfall Data for: National Avg., US" heading. The rainfall values can be adjusted by the user by using the advanced settings menu under the "Rainfall Data" tab.

[1] Hourly Precipitation Data (HPD) Network, Version 1 beta - https://catalog.data.gov/dataset/u-s-hourly-precipitation-data

Volume Capture Goal

The desired volume of rainfall able to be captured added by the BMPs is set as a goal. This goal is calculated based upon the site's size and an amount that is related to either the total area of the site or only the impervious area. The default is set at ½ inch time the impervious area. This can be adjusted by using the edit goal button to the left of the "Volume Capture Goal" heading.

BMPs

The user picks the BMPs they would like to implement to meet the set goal. Initially the user must set the area where the BMP will be implemented, then the quantity or size (in the predetermined units) of the BMP. The tool then calculates the cost and volume each BMP will contribute to meeting the volume capture goal. The user can, if needed, adjust the cost estimates and/or the various specifications of each BMP – there are default values for these that were researched to find a typical cost and value or each. The cost calculation is performed by multiplying the cost per unit time the number of units, the annual maintenance cost is likewise calculated. The net present value is calculated for a life cycle set by default of 30 years with an annual discount rate of 3%. These values can be adjusted using the "Advanced Settings" under the "Financial Costs" tab.

Costs

The cost of each BMP is calculated by the following formula:

$$CC_{bmp} = CE_{bmp} * U_{bmp}$$

The annual maintenance costs are:

$$MC_{bmp} = ME_{bmp} * U_{bmp}$$

And the net present value:

$$NPV_{bmp} = \sum_{m=0}^{f} \frac{CC_{bmp}}{(1+i)^{m*l}} + \sum_{yr=0}^{n} \frac{MC_{bmp}}{(1+i)^{yr}}$$

Where CC_{bmp} is the construction cost of the units of BMPs (U_{bmp}), CE_{bmp} is the construction cost estimate per unit, ME_{bmp} is the maintenance cost estimate per unit, l is the estimated lifetime or the BMP, n is the years in lifecycle and i is the discount rate, f is the number of time the BMP will need to be replaced in the lifecycle. Note this assumes that the BMP will need maintenance in the year it is installed or replaced.

Volume Calculations

The BMPs are grouped by various categories and are listed below, also listed are the unit of measure that the user is asked to input and the type of area where the BMP will be installed, note that if this is "any" the user must pick a location.

BMP	Category	Unit	Installed on
Green Roof	Roof Water Capture	ft^2	roof
Rain Barrel	Roof Water Capture	number	none
Cistern	Roof Water Capture	number	none
Foundation/Perimeter Drain	Roof Water Capture	ft	any
Rain Garden	Roof Water Redirection	ft^2	any
Planter Boxes	Roof Water Redirection	planters	any
Drywell	Roof Water Redirection	number	none
Trees	Landscaping	trees	any
Amended Soil	Landscaping	ft^2	any
Bio-Swales	Landscaping	ft	any
Urban Farming/Gardening	Landscaping	ft^2	any
Vegetation Filter Strip	Landscaping	ft	any
Native Vegetation	Landscaping	ft^2	any
Parking Lot Swales	Directing Runoff	ft	parking
Roadside Swales	Directing Runoff	ft	any
Permeable Patio	Permeable Paving	ft^2	patio
Permeable Parking	Permeable Paving	ft^2	parking
Permeable Sidewalks	Permeable Paving	ft^2	sidewalk
Permeable Driveway	Permeable Paving	ft^2	drive
Permeable Streets	Permeable Paving	ft^2	street

As the user defines the site and adds the desired BMPs the calculator estimated the volume that these BMPs will provide to capture rainfall. In general, the way this calculation is performed by either using the volume of the BMP where the whole volume is used for Rain Barrels, Cisterns, and Drywells, or using the porosity of the BMPs material, and or a combination of these. The following tables documents the method use for each BMP.

Green Roof

Specification	Initial Default Value
Construction Cost	$\$11.98/Ft^2$
Maintenance Cost	$\$0.75/Ft^2$
Typical Useful Life	40 Years
Growth Medium	6 Inches
Growth Medium Porosity	0.3
Drainage Layer	2 Inches
Drainage Layer Porosity	0.25

The volume of water able to be held in the green roof is calculated by:

$$VC_{GR} = (D_{GM} * P_{GM} + D_{DL} * P_{DL}) * A_{GR}$$

Where VC_{GR} is the volume captured from the area of the green roof (A_{GR}) with growth medium depth of D_{GM} and porosity of P_{GM} and drainage layer depth of D_{DL} and porosity of P_{DL}.

Rain Barrel

Specification	Initial Default Value
Construction Cost	\$2/Gallon
Maintenance Cost	\$0.55/Gallon
Typical Useful Life	20 Years
Volume	55 Gallons

The volume of water able to be held in the amount of rain barrel is calculated by:

$$VC_{RB} = V_{RB} * N_{RB}$$

Where VC_{RB} is the volume captured from the number of rain barrels (N_{GR}) with volume of each of V_{RB}.

Cistern

Specification	Initial Default Value
Construction Cost	\$1.37/Gallon
Maintenance Cost	\$0.14/Gallon
Typical Useful Life	40 Years
Volume	1000 Gallons

The volume of water able to be held in the amount of rain barrel is calculated by:

$$VC_C = V_C * N_C$$

Where VC_C is the volume captured from the number of cisterns (N_C) with volume of each of V_C.

Foundation/Perimeter Drain

Specification	Initial Default Value
Construction Cost	\$45/Ft
Maintenance Cost	\$0/Ft
Typical Useful Life	40 Years
Top Width	36 Inches
Curb Depth	6 Inches
Aggregate Depth	2 Inches
Aggregate Porosity	0.25
Pipe Diameter	4 Inches

The volume of water able to be held in the amount of green roof is calculated by:

$$VC_{FD} = \left\{[(D_{FD} * P_{FD} + CD_{FD}) * TW_{FD}] + \pi * \left(\frac{PD_{FD}}{2}\right)^2\right\} * L_{FD}$$

Where VC_{FD} is the volume captured from the length of the foundation/perimeter drain (L_{FD}), with top width of TW_{FD}, curb depth of CD_{FD}, aggregate depth of D_{FD}, aggregate porosity of P_{FD}, and pipe diameter of PD_{FD}.

Rain Garden

Specification	Initial Default Value
Construction Cost	\$6.07/Ft^2
Maintenance Cost	\$0.41/ Ft^2

Specification	Initial Default Value
Typical Useful Life	22.5 Years
Ponding Depth	8 Inches
Amended Soil	8 Inches
Amended Soil Porosity	0.35
Aggregate Depth	2 Inches
Aggregate Porosity	0.25

The volume of water able to be held in the amount of rain garden is calculated by:

$$VC_{RG} = (SD_{RG} * SP_{RG} + AD_{RG} * AP_{RG} + PD_{RG} * 0.667) * A_{RG}$$

Where VC_{FD} is the volume captured from the area of the rain garden (A_{RG}), with ponding depth of PD_{RG} amended soil depth of SD_{FD}, amended soil porosity of SP_{RG}, aggregate depth of AD_{RG}, aggregate porosity of AP_{RG}. Note that as an approximation for the sloping sides of the ponding area the volume of ponding is scaled back by two thirds.

Planter Box

Specification	Initial Default Value
Construction Cost	$9.46/Ft^2
Maintenance Cost	$1.18/ Ft^2
Typical Useful Life	25 Years
Size	25 Ft^2
Ponding Depth	4 Inches
Soil	12 Inches
Soil Porosity	0.4
Aggregate Depth	12 Inches
Aggregate Porosity	0.25

The volume of water able to be held in the number of planting boxes is calculated by:

$$VC_{PB} = \{[(SD_{PB} * SP_{PB} + AD_{PB} * AP_{PB} + PD_{PB})]\} * A_{PB} * N_{PB}$$

Where VC_{PB} is the volume captured from the number of planting boxes (N_{PB}), with area A_{PB}, ponding depth of PD_{PB} soil depth of SD_{PB}, soil porosity of SP_{PB}, aggregate depth of AD_{PB}, aggregate porosity of AP_{PB}.

Drywell

Specification	Initial Default Value
Construction Cost	$250
Maintenance Cost	$20
Typical Useful Life	70 Years
Volume	50 Gallons

The volume of water able to be held in the amount of drywell is calculated by:

$$VC_D = V_D * N_D$$

Where VC_D is the volume captured from the number of drywells (N_D) with volume of each of V_D.

Tree

Specification	Initial Default Value
Construction Cost	$250
Maintenance Cost	$180
Typical Useful Life	80 Years
Canopy	200 Ft^2
Canopy Porosity	0.01 – this is to account for rainwater held by the leaves
Tree Pit	16 Ft^2
Amended Soil	18 Inches
Amended Soil Porosity	0.4 accounts for the tree's root system

The volume of water able to be held in the number of trees is calculated by:

$$VC_T = (CA_T * CP_T + SD_T * SP_T * TP_T) * N_T$$

Where VC_T is the volume captured from the number of trees (N_T) with canopy area of CA_T, with canopy porosity of CP_T, with tree pit area of TP_T, with amended soil depth of SD_T, with amended soil porosity of SP_T – note that this assumes that only the first foot of canopy holds rainwater.

Amended Soil

Specification	Initial Default Value
Construction Cost	$0.29/$Ft^2$
Maintenance Cost	$0.0/ Ft^2
Typical Useful Life	100 Years
Amended Soil	6 Inches
Amended Soil Porosity	0.35

The volume of water able to be held in the amount of amended soil is calculated by:

$$VC_{AS} = SD_{AS} * SP_{AS} * A_{AS}$$

Where VC_{AS} is the volume captured from the area of the amended soil (A_{AS}), with amended soil depth of SD_{AS}, amended soil porosity of SP_{AS}.

Bio-Swale

Specification	Initial Default Value
Construction Cost	$17.58/$Ft^2$
Maintenance Cost	$0.26/ Ft^2
Typical Useful Life	20 Years
Ponding Depth	6 Inches
Amended Soil	8 Inches
Amended Soil Porosity	0.35

The volume of water able to be held in the amount of bio-swale is calculated by:

$$VC_{BS} = (SD_{BS} * SP_{BS} + PD_{BS} * 0.667) * A_{BS}$$

Where VC_{BS} is the volume captured from the area of the bio-swale (A_{BS}), with ponding depth of PD_{BS} amended soil depth of SD_{BS}, amended soil porosity of SP_{BS}. Note that as an approximation for the sloping sides of the ponding area the volume of ponding is scaled back by two thirds.

Urban Farming/Gardening

Specification	Initial Default Value
Construction Cost	$0.29/Ft^2
Maintenance Cost	$0.0/ Ft^2
Typical Useful Life	100 Years
Amended Soil	6 Inches
Amended Soil Porosity	0.35

The volume of water able to be held in the amount of amended soil is calculated by:

$$VC_{UG} = SD_{UG} * SP_{UG} * A_{UG}$$

Where VC_{UG} is the volume captured from the area of the amended soil (A_{UG}), with amended soil depth of SD_{UG}, amended soil porosity of SP_{UG}.

Vegetation Filter Strip

Specification	Initial Default Value
Construction Cost	$0.59/Ft^2
Maintenance Cost	$0.04/ Ft^2
Typical Useful Life	30 Years
Top Width	12 Inches
Ponding Depth	12 Inches
Amended Soil	8 Inches
Amended Soil Porosity	0.35
Aggregate Depth	8 Inches
Aggregate Porosity	0.25

The volume of water able to be held in the amount of vegetation filter strip is calculated by:

$$VC_{VFS} = (SD_{VFS} * SP_{VFS} + AD_{VFS} * AP_{VFS} + PD_{VFS} * 0.667) * TW_{VFS} * L_{VFS}$$

Where VC_{VFS} is the volume captured from the area of the vegetation filter strip (L_{VFS}), with a top width of TW_{VFS}, with ponding depth of PD_{VFS} amended soil depth of SD_{VFS}, amended soil porosity of SP_{VFS}, aggregate depth of AD_{VFS}, aggregate porosity of AP_{VFS}. Note that as an approximation for the sloping sides of the ponding area the volume of ponding is scaled back by two thirds.

Native Vegetation

Specification	Initial Default Value
Construction Cost	$0.19/Ft^2
Maintenance Cost	$0.05/ Ft^2
Typical Useful Life	100 Years
Amended Soil	8 Inches
Amended Soil Porosity	0.35

The volume of water able to be held in the amount of native vegetation is calculated by:

$$VC_{NV} = SD_{NV} * SP_{NV} * A_{NV}$$

Where VC_{NV} is the volume captured from the area of the native vegetation (A_{NV}), with amended soil depth of SD_{NV}, amended soil porosity of SP_{NV}.

Parking Lot Swales

Specification	Initial Default Value
Construction Cost	$36.93/Ft^2
Maintenance Cost	$1.83/ Ft^2
Typical Useful Life	25 Years
Top Width	18 Inches
Amended Soil	8 Inches
Amended Soil Porosity	0.35
Aggregate Depth	8 Inches
Aggregate Porosity	0.25

The volume of water able to be held in the amount of parking lot swales is calculated by:

$$VC_{PLS} = (SD_{PLS} * SP_{PLS} + AD_{PLS} * AP_{PLS}) * TW_{PLS} * L_{PLS}$$

Where VC_{PLS} is the volume captured from the area of the parking lot swales (L_{PLS}), with a top width of TW_{PLS}, amended soil depth of SD_{PLS}, amended soil porosity of SP_{PLS}, aggregate depth of AD_{PLS}, aggregate porosity of AP_{PLS}.

Roadside Swales

Specification	Initial Default Value
Construction Cost	$36.93/Ft^2
Maintenance Cost	$1.83/ Ft^2
Typical Useful Life	25 Years
Top Width	24 Inches
Amended Soil	6 Inches
Amended Soil Porosity	0.35
Aggregate Depth	12 Inches
Aggregate Porosity	0.25

The volume of water able to be held in the area of roadside swales is calculated by:

$$VC_{RS} = (SD_{RS} * SP_{RS} + AD_{RS} * AP_{RS}) * TW_{RS} * L_{RS}$$

Where VC_{PLS} is the volume captured from the area of the roadside swales (L_{PLS}), with a top width of TW_{PLS}, amended soil depth of SD_{PLS}, amended soil porosity of SP_{PLS}, aggregate depth of AD_{PLS}, aggregate porosity of AP_{PLS}.

Permeable Pavement

Specification	Initial Default Value				
Area Paved	Patio	Parking	Sidewalk	Driveway	Street
Construction Cost	$8.68/Ft^2	$8.68/Ft^2	$8.68/Ft^2	$8.68/Ft^2	$8.68/Ft^2
Maintenance Cost	$0.02/ Ft^2	$0.02/ Ft^2	$0.02/ Ft^2	$0.02/ Ft^2	$0.02/ Ft^2
Typical Useful Life	30 Years	30 Years	30 Years	30 Years	30 Years

Specification	Initial Default Value				
Bedding Depth	2 Inches	2 Inches	2 Inches	2 Inches	2 Inches
Bedding Porosity	0.25	0.25	0.25	0.25	0.25
Base Depth	4 Inches	4 Inches	4 Inches	4 Inches	4 Inches
Base Porosity	0.25	0.25	0.25	0.25	0.25
Sub-Base Depth	2 Inches	2 Inches	2 Inches	2 Inches	2 Inches
Cub-Base Porosity	0.25	0.25	0.25	0.25	0.25

The volume of water able to be held in the area of roadside swales is calculated by:

$$VC_{PP} = (BD_{PP} * BP_{PP} + BD_{PP} * BP_{PP} + SD_{PP} * SP_{PP}) * A_{PP}$$

Where VC_{PP} is the volume captured from the area of the roadside swales (A_{PP}), amended soil depth of SD_{PLS}, amended soil porosity of SP_{PLS}, aggregate depth of AD_{PLS}, aggregate porosity of AP_{PLS}.

Results

The results of the designed scenario are displayed in the set of tabs under the “Volume Capture” gauge. They are described below, and where appropriate the method of calculating the content of each.

Site Overview

This tab is a summary table of the land use/cover you have defined (or was defined for the user by the template). This includes the green improvements listed under the landcover each was built upon. Note that Rain Barrel, Cisterns and Drywells are not listed since they do not take up substantial area.

Volume

This tab is a summary table of the added volume capacity for storing stormwater generated by the green improvements in the user’s scenario. See the section “Volume Calculations” above for the detailed method of how each BMP’s volume enhancement is calculated.

Runoff

To assess the co-benefits of the volume control it is important to estimate runoff from the scenario given the rainfall expected. This is accomplished using the TR-55[2] method. By using the standard curve numbers for each of the land cover type, assuming all the land cover is hydraulically connected (this implies that the overall curve number is calculated by taking the area weighted average of the curve numbers of each of the different land cover categories). The hydrologic soil type is assumed to be C, but the user can change that if desired, and we use the ratio of initial abstraction to total cumulative

[2] https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

abstraction (λ) of 0.2 (the more nonlinear method with λ =0.05[3] has not yet been implemented). The following is a table of the curve numbers used:

Table 1: Default curve numbers for various land cover[4]

Land Cover	A Soil Curve Number	B Soil Curve Number	C Soil Curve Number	D Soil Curve Number
Impervious Area	98	98	98	98
Lawn in good condition	39	61	79	80
Flower Bed/Garden	34.5	59.5	74	79
Open	30	58	71	78
Shrub and Bushes	30	58	71	78
Wetlands	0	0	0	0
Raised Deck	77	69	91	94
Water	98	98	98	98

To account for the BMPs implemented, we change the value of the curve number (CN). For each land cover area, the CN above is adjusting to account for the additional volume captured by the BMPs on that land cover area.

The calculation of the total cumulative abstraction (S) from TR-55 is:

$$S = \frac{1000}{CN} - 10$$

Note that S is defined by[5]:

S = potential maximum retention after runoff begins (in)

Thus, when the BMP adds more volume control to a land use type, then that land use type curve number will change, and can be calculated. The volume V_{lc} capture potential for a land cover type with area A_{lc} before the BMPs are added can be expressed as:

$$V_{lc} = S_{lc} * A_{lc}$$

Once a BMP of area A_{gi} and volume VA_{gi} is added:

$$V_{with\ gi} = S_{lc} * \left(A_{lc} - A_{gi}\right) + V_{gi}$$

For the land cover area with the BMPs the total cumulative abstraction can be expressed as:

$$S_{with\ gi} = \frac{V_{with\ gi}}{A_{lc}} = \frac{S_{lc} * \left(A_{lc} - A_{gi}\right) + V_{gi}}{A_{lc}}$$

[3] http://ponce.sdsu.edu/hawkins_initial_abstraction.pdf
[4] TR-55 Table 2.2a
[5] http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf page 2.1

Therefore, the new curve number is represented by:

$$CN_{with\ gi} = \frac{1000}{S_{with\ gi} + 10}$$

These previous equations all assume the ratio of initial abstraction to total cumulative abstraction (λ) is the traditional value of 0.2. In other words, the initial abstraction (the amount of rain that must fall before there is any runoff) is:

$$I_a = \lambda * \ S_{sith\ gi}$$

The final runoff value for runoff ($Q_{with\ gi}$ – the inches of rain the runs off the site) if the amount of rainfall (P – measured in inches) is greater than I_a, is:

$$Q_{with\ gi} = \frac{(P - 0.2 * S_{with\ gi})^2}{P + 0.8 * S_{with\ gi}}$$

This of course is for any given rainfall, to estimate the annual runoff from a given scenario the calculator uses the daily rain fall (see section Rainfall Data above) and calculates the daily runoff and sums this over the entire year.

Costs

The costs table is self-explanatory. The cost for each item is listed in the table include the installation cost, the maintenance cost and net present value of the cost over a life cycle and discount rate (initially define as 30 years and 3.1% - these can be adjusted in the advanced settings tab).

Benefits

The benefits are broken out by who get the benefit; there is a table representing estimates of the benefits the home/building owner will receive from reduced cost of energy, a table of estimated community benefits and finally a table of the estimated real estate value increase as a percent of the current value – see https://www.cnt.org/sites/default/files/publications/GSI-Impact-on-Property-Values.pdf for a full discussion of how these benefits are arrived at. The following table lists the owner and community benefits and their value.

Benefit	Description	Annual Value	Unit
Owner Benefits			
Reduced Energy Use from Trees	Trees save energy for nearby buildings.	\$36	Per Tree
Reduced Energy Use from Green Roof		\$18	Per 100 ft^2
Community Benefits			

Reduced Air Pollutants from Trees	Trees absorb and redirect air pollution.	$0.18	Per Tree
Carbon Dioxide Sequestration from Trees	Trees take in CO_2	$0.12	Per Tree
Compensatory Value of Trees	Trees add value to property the neighborhood.	$275	Per Tree
Water Treatment Cost Reduction	Using the volume of reduced runoff, the savings of not treating the amount of water absorbed by the BMPs is calculated by using the cost of treating water.	$29.94	Per acre feet[6]
Groundwater Replenishment	Using the volume of reduced runoff, the value of replenishing groundwater.	$86.42	Per acre feet

[6] An acre foot is a common unit of measure in hydrology and is equal to the volume of one foot of water on an acre of land, this is equal to 43,550 cubic feet.