User Guide

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Domain: https://clasic.erams.com/

Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC)

CATENA ANALYTICS

One Water Solutions Institute

Colorado State University

CONTENTS

EXECUTIVE MESSAGE

Catena Analytics offers powerful platforms for building accessible and scalable analytical tools and simulation models that can be accessed via desktop or mobile devices. Our team has spent the last decade developing the Environmental Resource Assessment and Management System (eRAMS), an open-source technology that provides cloud-based geospatially-enabled software solutions as online services and a platform for collaboration, development, and deployment of online tools. Our services are used to assist with strategic and tactical decision making for sustainable management of land, water and energy resources. Thank you for choosing Catena Analytics and the eRAMS platform to meet your data, modeling, analysis and geospatial needs.

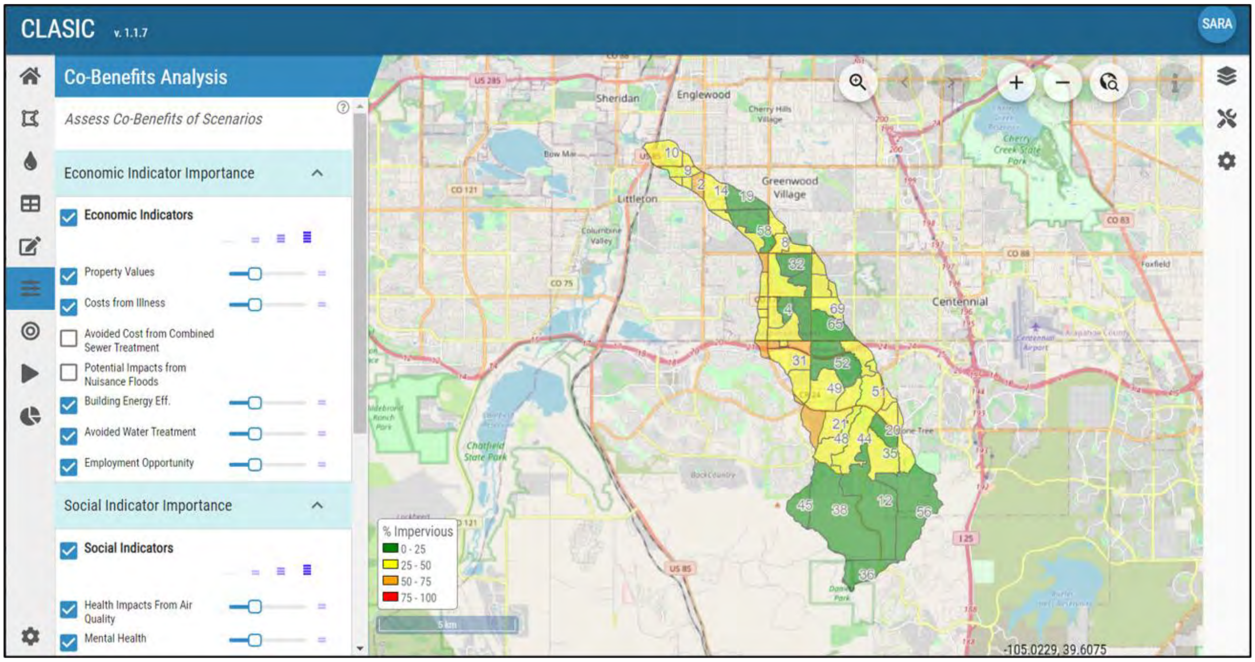
WHO SHOULD USE THIS GUIDE

This guide is a tutorial to get you started using eRAMS and the Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC). The guide provides instructions for commonly performed tasks and uses of the tool. This tool is intended for use by managers and operators of regulated stormwater systems, managers and operators of any unit of municipal government with dedicated funding for stormwater management and consultants to those groups.

NEED HELP?

After reviewing the guide and video tutorials, if you need additional assistance we are here to help! This guide is designed to provide instruction on commonly performed operations and answers to many frequently asked questions. If you find any aspect of the tool challenging or missing information from this guide, please engage an eRAMS expert to guide you through any hurdles. Contact us at: eramsinfo@gmail.com

INTRODUCTION



PURPOSE

The Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC) tool is a screening tool utilizing a lifecycle cost framework to support stormwater infrastructure decisions on extent and combinations of green, hybrid green-gray and gray infrastructure practices. The tool is hosted on the eRAMS platform which includes a geographical information system (GIS) interface and interacts with national databases to upload data for the modeled area.

DESCRIPTION

The CLASIC tool is intended for screening combinations of practices but is not intended for optimization of designs. Analyses that CLASIC will enable for users versus analyses outside of the scope of CLASIC are contrasted in Figure 1.

CLASIC will enable users to

- Assess scenarios of stormwater infrastructure via functional unit analysis for robust decision making based on preferences to evaluate:
  - Regulatory compliance
  - Runoff volume reduction
  - Water quality
  - Social and environmental benefits
  - Lifecycle cost
- Couple financial decision with holistic consideration of benefits (primary and secondary)
- Conduct analysis from neighborhood to watershed scale

Analyses not included in CLASIC

- Site specific design of stormwater infrastructure
- Comparison of spatial distribution of infrastructure within sub-unit or subcatchment
- Algorithms for optimization of design

Figure 1: CLASIC tool functionality

Tool Outputs

Three categories of outputs are provided by the CLASIC tool; life cycle costs (LCC), co-benefit analysis and performance (Figure 2).

Life Cycle Cost – The LCC is structured to provide feasibility level municipal budget estimates over time for a variety of SCM construction and maintenance costs.

Performance – Performance of scenarios will be estimated in terms of hydrology (e.g. peak runoff and volume reduction) and pollutant load reduction.

Co-Benefits - The co-benefits analysis will be informed via multi-criteria decision analysis (MCDA) output. The MCDA provides quantitative output to compare co-benefits across scenarios of technology selection.

These three components of outputs are intended to work in tandem to inform decisions on scenarios. When a user views outputs, the user will have the option to create new scenarios based on knowledge gained from the previous scenario outputs.

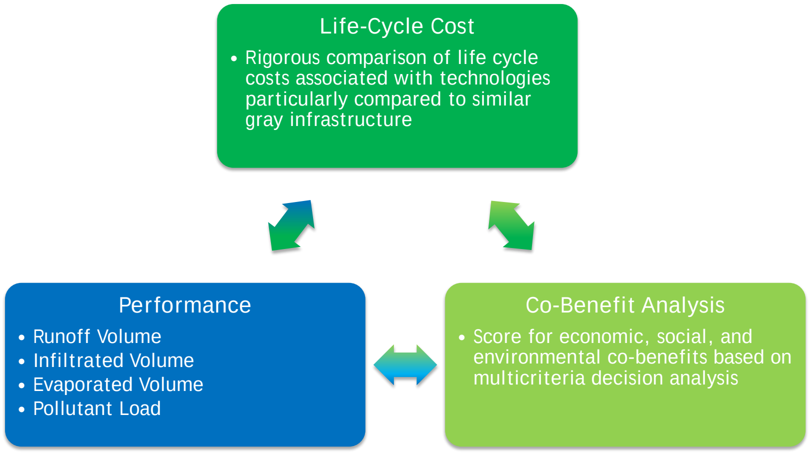


Figure 2: CLASIC tool outputs

SOFTWARE AVAILABILITY

Domain

https://clasic.erams.com/

Documentation URL

https://clasic.erams.com/

Acknowledgements

Development of this tool was sponsored by the Water Research Foundation, US Environmental Protection Agency, and National Science Foundation Urban Water Innovation Network.

AUTHORIZED USE PERMISSION

The information contained in the Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs tool (the "Service") is for general information purposes only. Colorado State University's One Water Solutions Institute ("CSU-OWSI") assumes no responsibility for errors or omissions in the contents of the Service. In the Service (tool link), you agree to hold neither the creators of the software platform nor CSU-OWSI liable for any action resulting from use or misuse of the Service. In no event shall CSU-OWSI be liable for any special, direct, indirect, consequential, or incidental damages or any damages whatsoever, whether in an action of contract, negligence or other sort, arising out of or in connection with the use of the Service or the contents of the Service. CSU-OWSI reserves the right to make additions, deletions, or modification to the contents of the Service at any time without prior notice.

GETTING STARTED

QUICK START

1. Go to clasic.erams.com
2. Create an account or log-in
3. The icons on the left panel will guide you through the steps of the CLASIC tool (Figure 3).

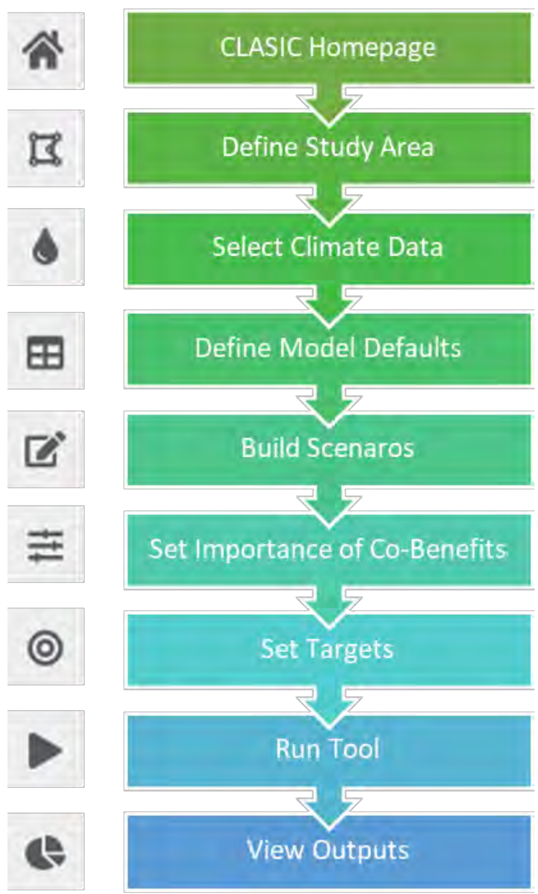


Figure 3: CLASIC tool quick start guidance

SYSTEM REQUIREMENTS

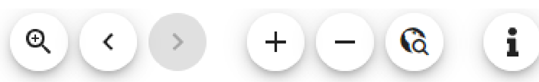
A modern web-browser is required to connect and run CLASIC. Browser options include: Google Chrome v.69, Mozilla Firefox v.62, Safari v.11.1, and Microsoft Edge v.17. ***Note: the CLASIC tool is not compatible with Internet Explorer.***

USING THE TOOL

DEFINE STUDY AREA

Create Project

1. You can either create a new project using the default project creator, use a shapefile to create a new project, clone a previously existing project, or load a project you have previously created.
2. Navigate the map using buttons on the top right corner of the map pane. Zoom to the area of interest on the map by selecting the search button and entering a zip code or city name.



3. To create a project, specify the project boundary by selecting one of the following methods:

- *Draw on map*: The options for selection of the geographic region of interest, i.e. study area, include the area defined by a rectangle (from corner to corner) or area within a free-hand polygon.
- *Known boundaries*: Select a study area from known boundaries, e.g. cities or HUC 12-digit Watersheds.
- *User Supplied Layer*: For this option, first upload your own shapefile using the User-Supplied layer option. The shapefile should define the project boundary and subunits (if desired). At minimum, .shp, .shx and .dbf file extensions must be included. Optional file extensions include .prj, .xml, .sbn, or .sbx. The shapefile may include any or all attributes that are used as inputs necessary to run the CLASIC tool including: ID, % Open, % Low, % Medium, % High, % Other, % Imperviousness, Slope, and/or Soil Group. You will be directed to specify attributes which correspond to CLASIC inputs, or you may use national datasets.
    - **ID:** The project area ID or the unique ID for each individual sub-unit. The ID should not include symbols or text longer than 15 characters.
    - **% Open Area:** Percent of land cover best characterized by open space. The total land cover percentages from open, low, medium, high and other should equal 100%. If this is left blank, NLCD data will be used to populate this category.
    - **% Low Area:** Percent of land cover best characterized by low intensity development. The total land cover percentages from open, low, medium, high and other should equal 100%. If this is left blank, NLCD data will be used to populate this category.
    - **% Medium Area:** Percent of land cover best characterized by medium intensity development. The total land cover percentages from open, low, medium, high

and other should equal 100%. If this is left blank, NLCD data will be used to populate this category.

- **% High Area:** Percent of land cover best characterized by high intensity development. The total land cover percentages from open, low, medium, high and other should equal 100%. If this is left blank, NLCD data will be used to populate this category.
- **% Other Area:** Percent of land cover best characterized by other, non-urban area. The total land cover percentages from open, low, medium, high and other should equal 100%. If this is left blank, NLCD data will be used to populate this category.
- **% Impervious:** Percent of area covered by connected impervious area. If this is left blank, NLCD data will be used to populate this category.
- **Slope:** Watershed slope or grading of the area. If this is left blank, U.S. SSURGO dataset will be used to populate this category.
- **Soil Group:** Hydrologic soil type, should be defined as type A, B, C, D, or Other. If this is left blank, U.S. SSURGO dataset will be used to populate this category.

Select Subunits and Data Sources

1. **Specify Project Subunits**. You can choose to develop a project as a single subunit or divide the project into multiple subunits. CLASIC enables users modify parameters such as imperviousness, soil type, and land cover on per subunit basis, as well as to add technologies to individual subunits. These subunits could be selected from nationally available polygon databases such as US Census Tracts, Block Groups, or Blocks. Census blocks are the smallest unit of analysis defined by US Census bounded by physical features such as roads or waterways and are the building blocks for all Census Bureau building blocks (e.g. block groups and tracts).
    - *Note that increasing the number of subunits does increase the run time for the* CLASIC tool. For a simple and quick run, select single subunit.
2. **Specify Land Use Source**. US National Datasets including National Land Cover Database (NLCD) 2001, NLCD 2006, NLCD 2011, and NLCD 2016 are available for analysis within the US. Data is extracted on land use type and impervious area from these databases. For other regions, users must provide a shapefile with land use percentages (i.e. open, low intensity, medium intensity, high intensity, and other) and imperviousness provided as attributes within the shapefile.
3. **Specify Soil Data Source**. Data sets from Soil Survey Geographic Database (SSURGO) can be used in the US. For other regions, users must provide a shapefile with slope and hydrologic soil type (i.e. A, B, C, D, or other) provided as attributes within the shapefile.
4. Specify the Project Name and select Create to define the project. When project area data has been extracted, the project is created. Move on to the next step (Climate Data).

Figure 4 shows the extent of the City of Centennial, CO from selection of known boundaries with Tracts selected as the subunit option and using NLCD 2016 and SSURGO soil data.

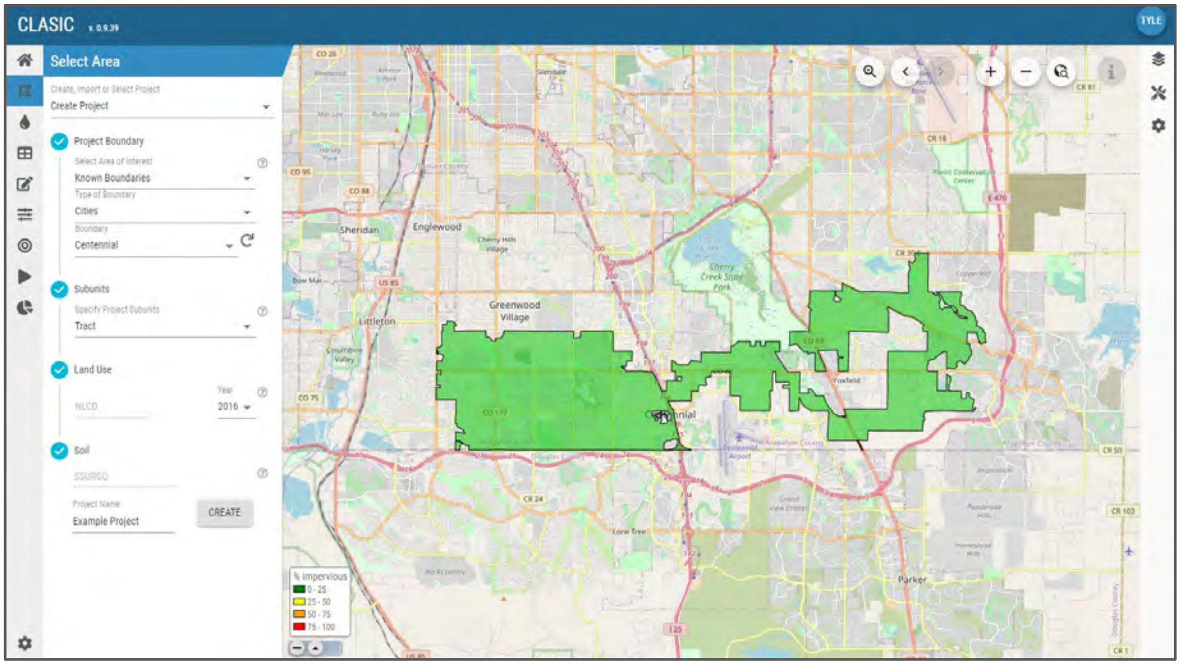


Figure 4: Define study area

Select Climate Data

1. Climate station data from EPA Better Assessment Science Integrating Point and Non-Point Sources (BASINS) Model are used in the CLASIC tool (USEPA, 2019). Select stations for each precipitation and evaporation data.
2. Select a precipitation station. Nearby EPA BASINS Model precipitation stations will automatically populate and appear on the map. Select the nearby station you would like to use. The data set populates in the lower right panel so that you can view the date range for the data set. Note: Precipitation may take a while to extract if it is the first time precipitation from that station is being accessed by any CLASIC user.
3. Select Start Year and End Year. This specifies the historical hydrologic period for which you would like to include for estimates of hydrologic performance of scenarios, which is output as average annual values. Inclusion of more years substantially increases the run time but does provide improved estimation of uncertainty of hydrologic performance. A range of 20 years is recommended, but a range of 10 years or less can be used to reduce the processing time of the model.

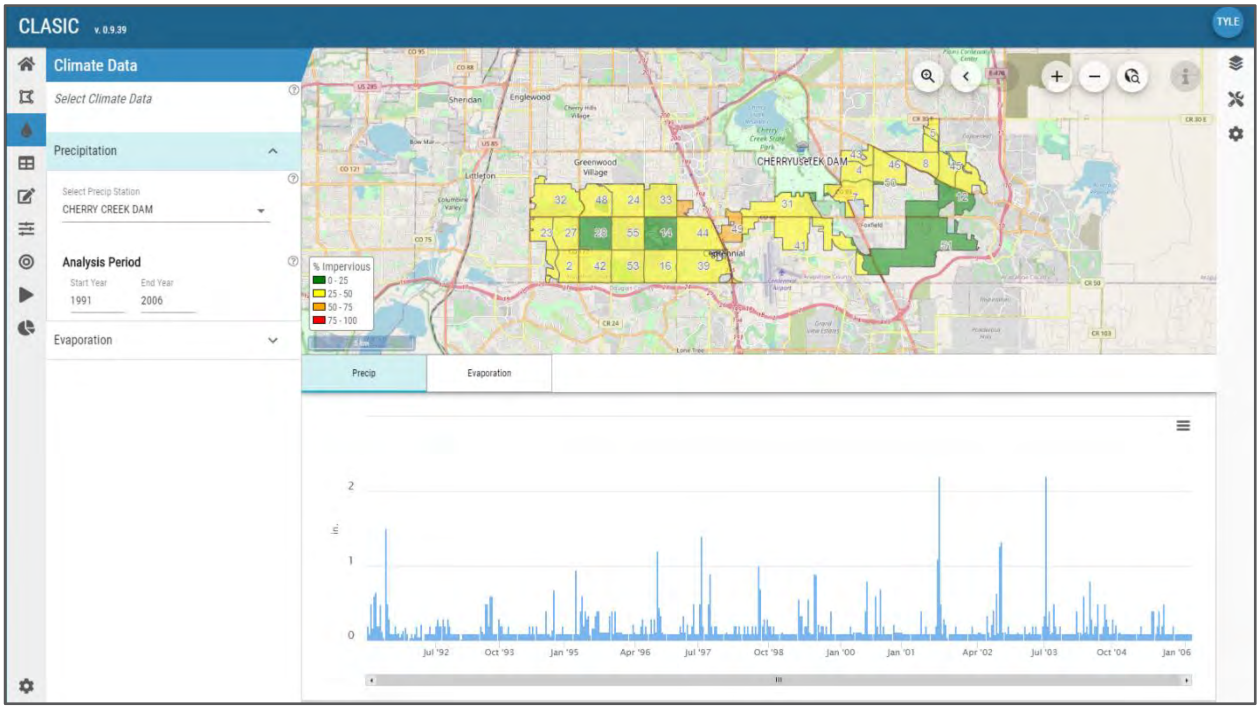


Figure 5: Selection of climate data stations

Figure 5 shows precipitation data available near the City of Centennial, CO.

4. Select an evaporation station. Available stations from the EPA BASINS model will automatically populate. Average daily evaporation rates are calculated from recorded climate data and summarized for each month. Monthly values for the selected station populates in the bottom right panel. Average daily evaporation rates can be modified by selecting the editing pencil and then modifying the value for any or each month in the bottom right panel. Values can then be saved or reverted back to original.

Figure 6 shows editable evaporation data available based on weather station data near the City of Centennial, CO.

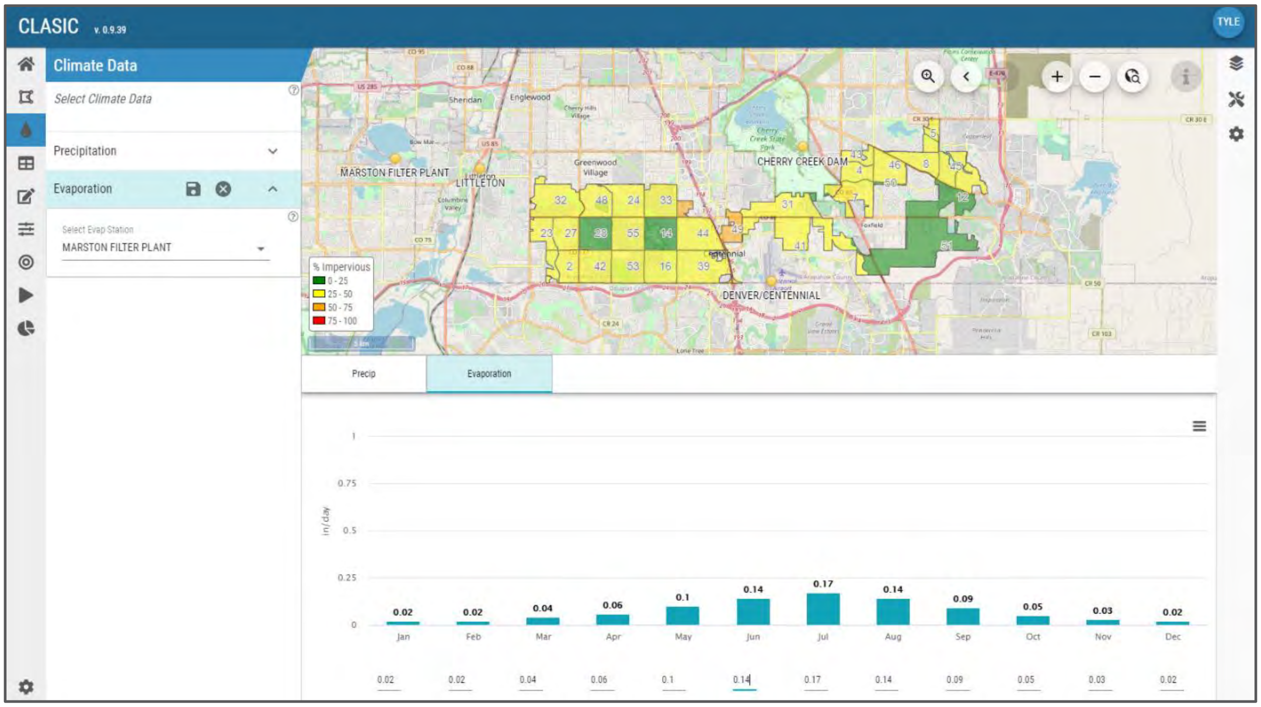


Figure 6: Editable evaporation data

Define Default Parameters

1. Default parameters used to generate CLASIC outputs can be modified. Reasonable outputs are provided without modification of default parameters, and there is no requirement to modify default parameters. The option to modify default parameters provides flexibility for the advanced user. Default parameters may be modified if desired for subunit characteristics (e.g., impervious area and land use type), water quality parameters, overland flow, Horton infiltration equation coefficients, technology effluent quality, and characteristics for computing lifecycle cost. Use the question mark icons for details on specific parameters for each category. To modify values in a category, select the pencil icon. Note that changes in the left panel affect values in the tables in bottom right. Values may be modified in either location. **All changes must be saved before moving onto future tabs** (click on disk icon; Figure 6). Changes may be reset to their default values using the revert button (see Figure 7 next to Overland Flow Length).
   - *Subunit Parameters*: A subunit contains several parameters which were calculated from national or user-supplied datasets. Parameters calculated include the area, % impervious, slope, and % land use types. Parameters for each individual subunit may be revised based on user preference using the table displayed in the analysis panel below the map. You may also choose to remove a subunit from analysis by selecting the “trash” icon on left under “Subunits.”
   - *Water Quality*: Concentrations of pollutant runoff are estimated using a weighted average based on land use from data collected from the National Stormwater Quality Database. In the case that local data is available on concentrations of

pollutants in runoff, default values can be modified. The concentration corresponding to land use type can be modified in the table in the left panel. In addition, the runoff concentration of an individual subunit may be revised using the table in the analysis panel (bottom right). Any changes to breakdown of land use will impact the pollutant runoff concentrations.

- *Overland Flow Length*: Overland flow length is the assumed distance water will travel before it becomes channelized flow and is used to estimate the hydrologic modeling parameter, width. Overland flow length is determined using a weighted average corresponding to land use. The overland flow length corresponding to land use may be modified in the table in the left panel which overland flow length of an individual subunit may be revised using the table in the analysis panel (bottom right). Any changes to breakdown of land use will impact the overland flow length.
- *Infiltration*: Infiltration is modeled using the Horton infiltration method. Infiltration parameters are applied based on the soil's hydrologic classification (drainage class A – D) as defined for each subunit. Soil hydrologic classification is determined for each subunit based on the most common soil drainage class (A – D) present in the subunit. Horton infiltration parameters as they correspond to soil type can be modified in the left panel, or the soils or infiltration parameters of an individual subunit may be revised using the table in the analysis panel (bottom right). Changes to soil type will override changes to other infiltration parameters.
- *Technology Effluent*: Technology effluent concentrations are applied to runoff that leaves the technology after being treated. Default values were developed based on performance summaries from the International BMP database. However, the values can be modified if better data exists. Use the table in the left panel to modify expected effluent concentrations for technologies. A blank value indicates no measurable change of effluent concentration.
- *Lifecycle Cost*: Lifecycle costs are calculated using a regional cost factor, study period (in years), and a user selected discount factor. The regional cost factor is set based on proximity to nearby cities. If the project area is greater than 100 miles from the nearest city with a regional adjustment factor, then the regional cost factor is set to 1. Changing the study period will affect the cost calculated for stormwater technologies considering annual maintenance and rehabilitation of the technology. The annual discount rate is used to bring future dollar amounts into present day dollars and is set by default to 0%.
- *Make sure to save (disk icon) before moving to Build Scenarios Icon.*

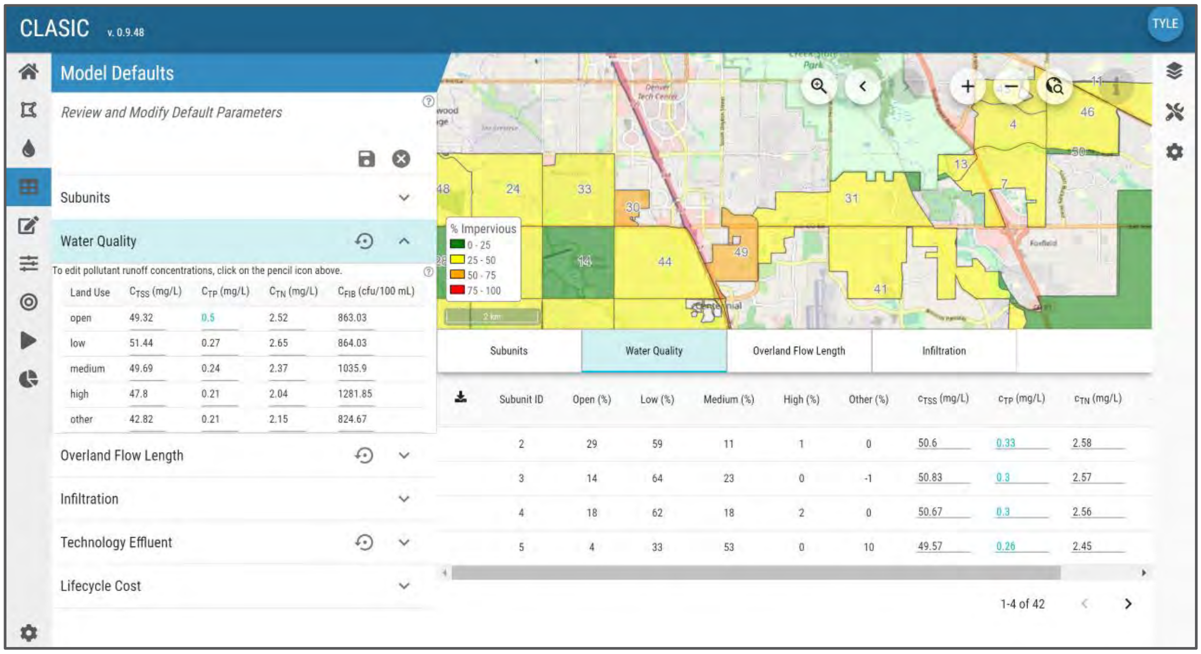


Figure 7: Option to modify default parameters

Build Scenarios

At this step, the baseline scenario can be modified and new scenarios of added technologies, climate change, and land use can be added (Figure 8).

Define Baseline Scenario

1. Start by defining the baseline scenario. This is the scenario that other scenarios created will be compared to. In most cases, the user would consider the baseline scenario as the current system. The baseline scenario does not include technologies unless added by the user. If the user would like to add technologies, click on "Baseline". If the Baseline model should include technologies, click the "Technologies" tab to add technologies. After technologies are added, the technology costs or the technology effluent can be edited using "Advanced Scenario Options".
    - Climate and land use cannot be modified for the baseline scenario from the parameter values uploaded in Climate Data and Default Parameters. These defaults can be modified in newly added scenarios.

Add Baseline Technologies

If user would like to technologies to the Baseline scenario, select the type of technology to be added to the study area. An input box appears in the left panel to specify technology parameters (see figure below).

Define Technology Parameters:

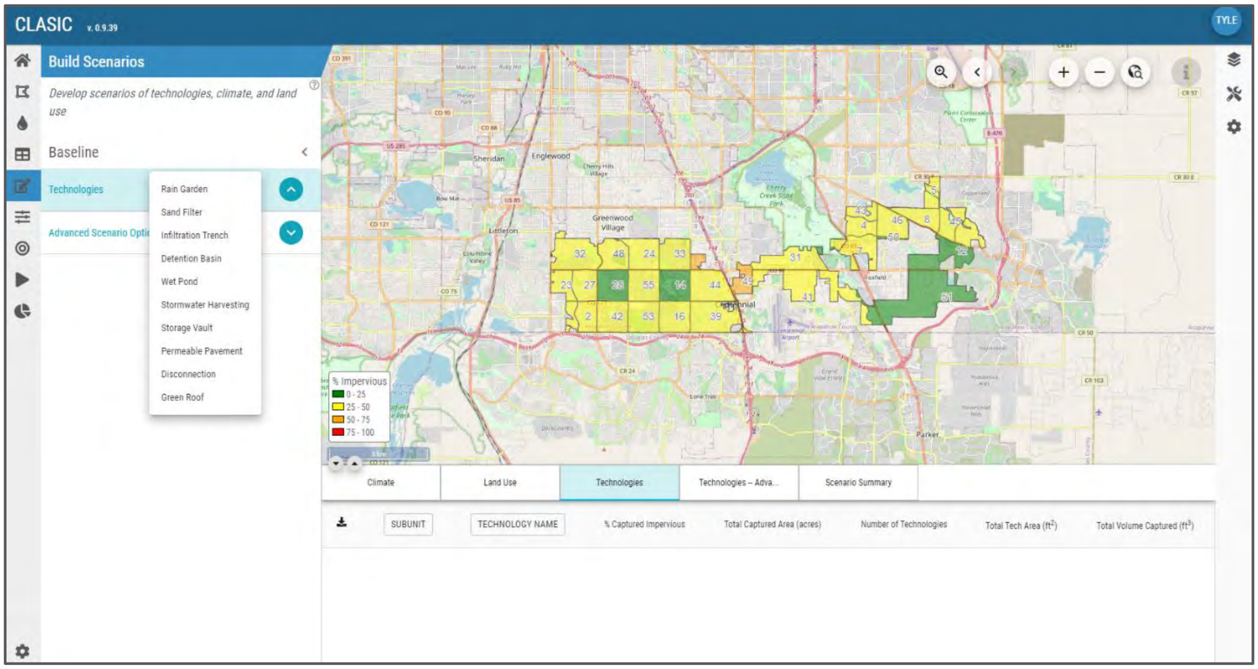


Figure 8: Selection of technologies to add to scenario

The user has the option to modify each technology based on the size of a unique technology, and other parameters that affect the hydrology, unit cost or co-benefits. Each parameter has a help option to provide more details regarding what it is. In addition, details on technology parameter selections are included in Appendix A.

- *Select technology placement:* Technologies can either be placed in surrounding pervious area provided by traditional landscaping or when pervious area is not available, will be placed in captured impervious area.
- *Select impervious area captured:* The percent of impervious area for which runoff drains to the technology with the parameters selected above. The total % Impervious Area Captured for all technologies applied in a subunit cannot exceed 100%.
- *Select depth to capture:* Precipitation depth assumed over the captured impervious area to inform the design of the technology and the number of technologies needed.
- *Select subunits for technology application:* Technologies can be applied on a subunit basis with selection as described below. Note that as technologies are added, they appear in the table in the right panel (see figure below). The user can view the area of the added technologies, number of technologies added, volume captured, and area treated for each subunit.
    - o *All:* Technologies are added to all subunits.
    - o *None:* Technologies are added to no subunits (use this selection to clear additions and restart)
    - o *Select on Map:* Use the interactive map to select subunits for technology addition by clicking on the subunits to place or remove the technology.

- o *Selection Criteria:* Select subunits by criteria such as size, land use type, impervious area, or soil type.
    - ▪ Use the dropdown menu for “Field” to select criteria
    - ▪ In “Op” select operation type (e.g., equal, less than or equal, or greater than or equal)
    - ▪ In “<value>”, select the value for which you will use for the criteria constraint
- Review table on right (Figure 9) to view area of stormwater technologies, how many technologies were added, volume and area captured, etc. to ensure that technology addition is consistent with what was intended and are feasible.

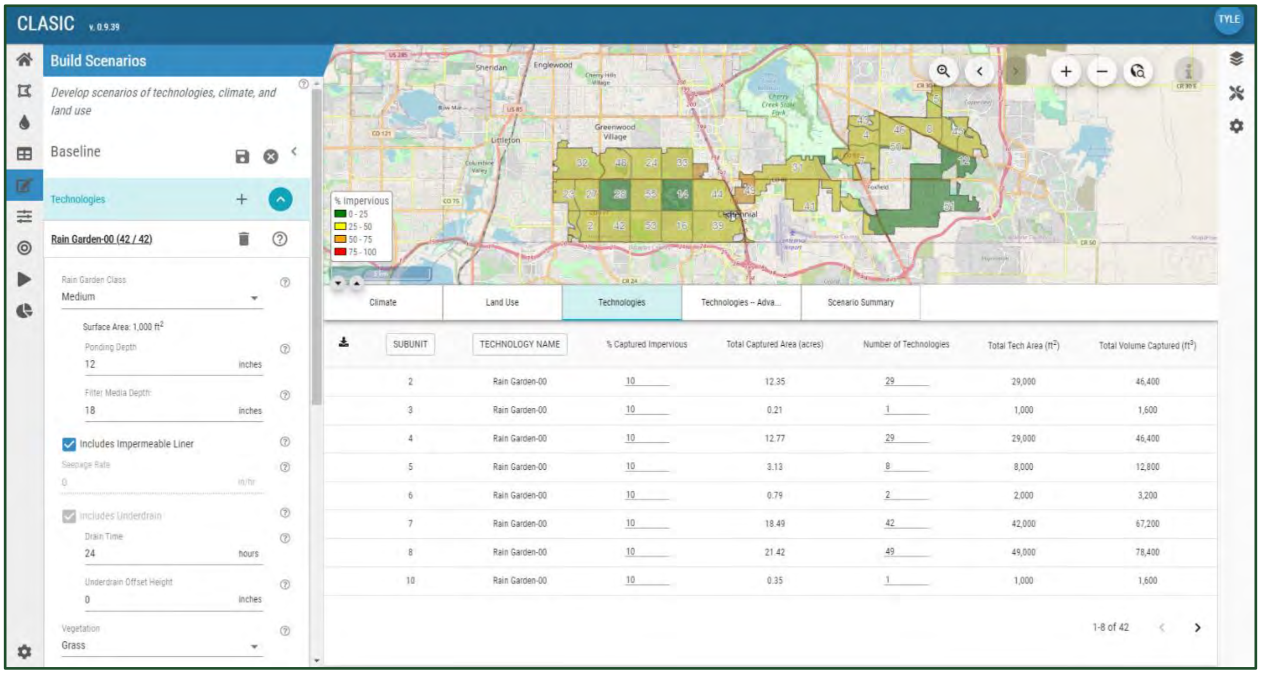


Figure 9: Summary table of added stormwater technologies

Advanced Scenario Options

The Advanced Scenario Options tab allows users to modify costs for each added technology or the effluent of runoff that leaves a technology through an underdrain.

- o *Cost modifications*: The construction, annual maintenance, or rehabilitation costs may also be edited for each technology type (Figure 10).

Construction costs reflect the activities and materials required to newly install or retrofit each technology (e.g., excavation, media, vegetation, etc.). Capital costs also include costs attributed to mobilization, demolition, engineering and additional contingency. Because they are location specific, land acquisition costs are not included in capital cost values.

Maintenance costs include activities that are performed for aesthetic reasons or to preserve the design life of the technology. These costs include routine activities (e.g., mowing or inlet grate cleaning) and periodic activities (e.g., spot revegetation or sediment removal) recommended for each technology.

Rehabilitation costs occur at time intervals equal to the expected design life of each technology and include replacement of most structural components, media, and vegetation, as appropriate for each technology.

When modifying the costs of a technology, the user may change the construction type between a new construction and previously constructed technology. If the user selects previously constructed, then capital costs are set to $0 and years to first rehabilitation may be adjusted to reflect when rehabilitation will be needed based on the average age of the previously constructed facilities. For example, rain gardens are assumed to have a life of 10 years before needing rehabilitation. If the rain gardens are a new construction, then the years to first rehabilitation is set to be the standard life of 10 years and capital costs are assumed to be $39,910 based on the size and number of components included in the rain garden. If however, the rain garden is set to previously constructed, and it is assumed the average age of previously constructed rain gardens is 7 years, then the years to first rehabilitation should be set to 3 and the capital costs will be set to $0. With this example the rain garden will incur rehabilitation costs on year 3 and then every ten years after that (i.e., year 13, year 23, etc.).

Figure 10: Modification of costs for technologies

Add Scenarios

Add new scenarios for analysis by clicking on the "+" icon next to Scenarios, or by duplicating a previously created scenario. Click on scenario name to modify characteristics for that scenario. Climate, land use, and technologies can be modified within scenarios. Consider what types of scenarios you are interested in. Some possible examples are below:

- *Addition of stormwater technologies to meet regulatory requirements:* To assess how addition of technologies compare to the baseline scenario, the newly added scenarios should include addition of technologies of interest. CLASIC will provide outputs that enable comparison of cost, performance, and co-benefits of these scenarios of technology addition.

- *Assess alternatives for a redevelopment area:* The baseline scenario would be setup to replicate the existing development area. If stormwater control measures (SCMs) are in place in the existing development area, those need to be added to the baseline scenario. Then, the user can add scenarios with modified land use and additional technologies to assess how those technologies cost, performance, and co-benefits compare to the existing development (baseline scenario).
- *Assess alternative stormwater technologies for a new development area:* The baseline scenario could be the undeveloped area. New scenarios could be added where land use type is modified and stormwater technologies are added. Hydrologic performance of those scenarios could be compared to the pre-development condition, and added scenarios could be compared for cost and co-benefits.
- *Assess performance of technologies in alternative future conditions:* The baseline scenario can be developed to represent current land use and climatic conditions. New scenarios can be created using the same SCMs, but with modified climate and land use to represent alternative future conditions.
- *Assess life-cycle cost trade-offs for SCMs:* Scenarios can be cloned and then using the advanced scenario options, the annual maintenance cost, years to first rehabilitation, or rehabilitation cost can be modified. Annual maintenance costs should be modified based on different maintenance activities and then various years to rehabilitation can be used to find when life-cycle costs become smaller or equivalent.

Modify Climate for Added Scenarios

You can either select a climate model to use or select percentage change in precipitation and evaporation manually.

Select Climate Model

Click to edit climate for a selected scenario. The Climate tab opens in the right panel (see figure below). Climate can be modified through comparing changes in 30-year monthly average precipitation and evaporation between a current and future year. The downscaled Multivariate Adaptive Constructed Analogs (MACA) datasets were used to project future changes in climate variables (Abatzoglou & Brown, 2012). The MACA dataset includes twenty models, which were downscaled for the continental United States (CONUS) at the grid size of 4 km (1/24 degree) under the RCP 4.5 and the RCP 8.5. Five future climate change scenarios (Table 1) were selected in CLASIC to capture a range with different temperature and precipitation ranges from the wettest projection, driest projection, hottest projection, the least warm projection, and one projection that reflected a middle of these ranges (Joyce et al., 2020). Users can select a climate projection scenario of interest or create multiple scenarios for different selections of climate projections to assess a range of climate scenario impact to stormwater technology performance.

Table 1: Sources of climate data for scenario developmet

	Hot	Warm	Wet	Dry	Middle
RCP 4.5	HadGEM2-ES365	MRI-CGCM3	CNRM-CM5	IPSL-CM5A-MR	NorESM1-M
RCP 8.5	HadGEM2-ES365	MRI-CGCM3	CNRM-CM5	IPSL-CM5A-MR	NorESM1-M
Model Agency	Met Office Hadley Center, UK	Meteorological Research Institute, Japan	National Centre of Meteorological Research, France	Institute Pierre Simon Laplace, France	Norwegian Climate Center, Norway

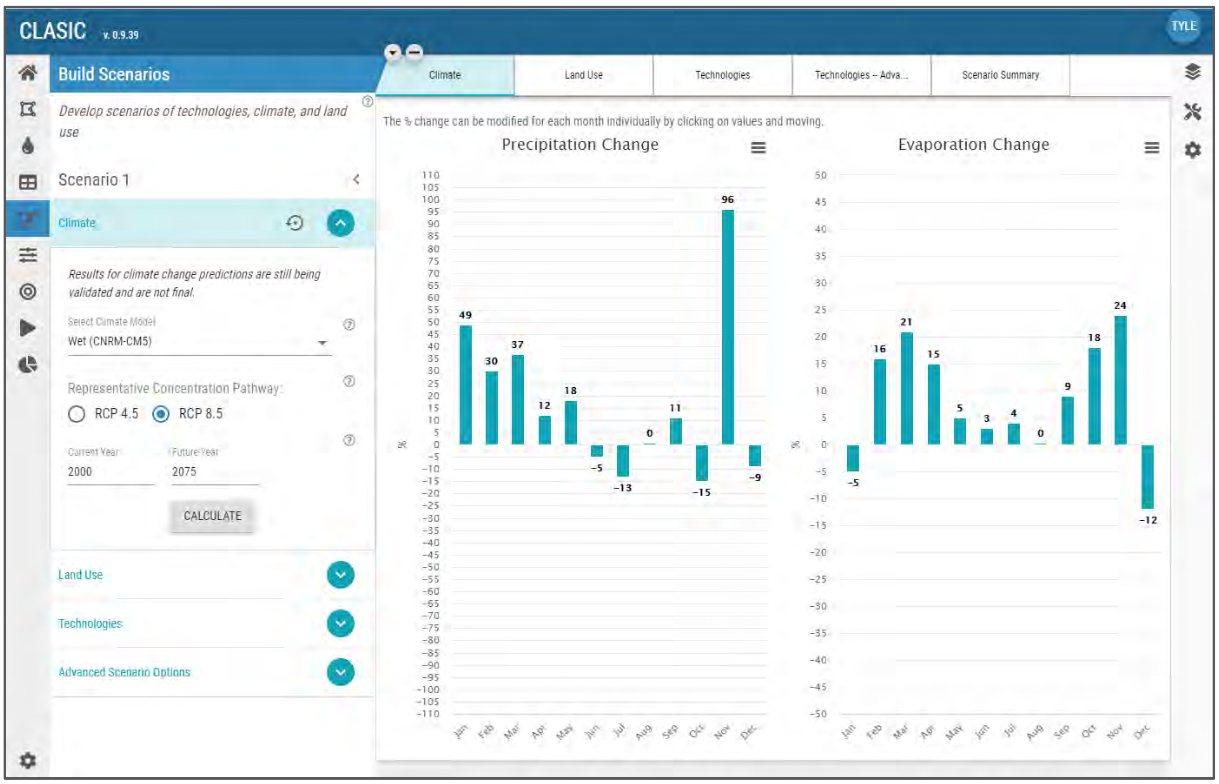


Figure 11: Modification costs for technologies

Manually Select Climate Conditions

Climate may also be changed using a uniform percentage change in precipitation and/or evaporation across all months, enter the percentage change (-10% change in precipitation, and +10% change in evaporation in the figure below). To apply different percent changes in each month, use the graph to click on values and modify (Figure 12).

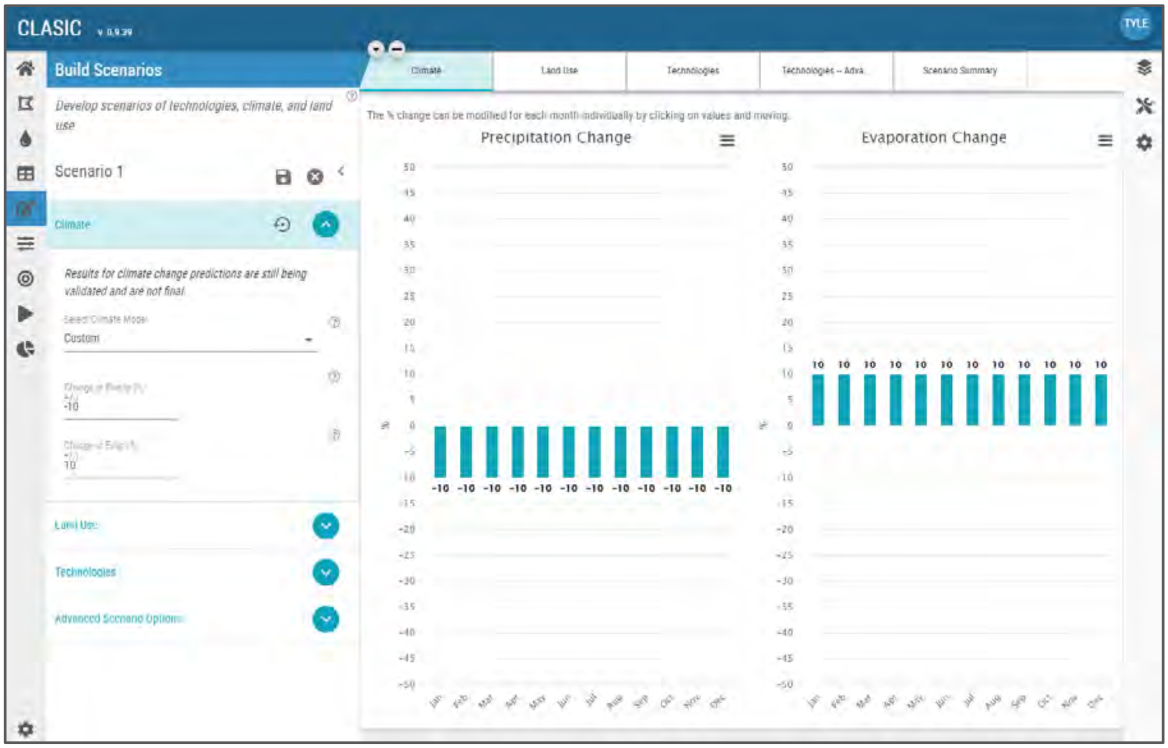


Figure 12: Manual selection of percentage change in monthly precipitation and evaporation for climate scenarios

Modify Land Use for Added Scenarios

Click to edit land use for a selected scenario (Figure 13). For each subunit the percentage of impervious area and/or percentage of land use type (i.e. low, medium, high, open) can be modified. When modifying the make up of land use type by percentage, the total must sum to 100%. Impervious area may be modified by increasing the imperviousness in each subunit by a certain percentage, or by setting the imperviousness in each subunit to defined value. Users may also edit the runoff concentrations and water quality parameters for each subunit within each scenario.

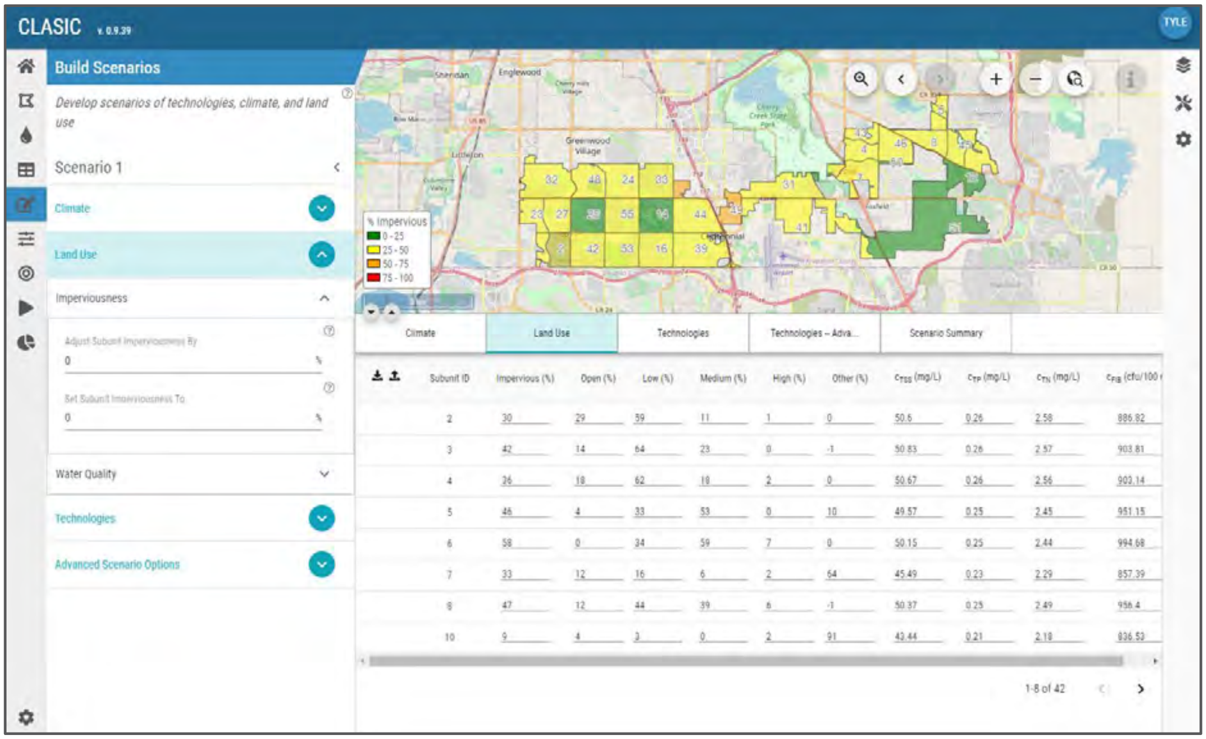


Figure 13: Table to modify impervious area and percentage of land cover categories

Add Technologies

See above instructions for adding technologies.

Advanced Scenario Options

Capital, annual maintenance, and rehabilitation unit costs may be modified for each technology. See above instructions for modifying the advanced scenario options.

CO-BENEFITS ANALYSIS

If you are interested in comparing co-benefits across scenarios, select importance factors to inform the co-benefits analysis that provides outputs for economic, social, and environmental performance (Figure 14):

1 = Not Important
2 = Somewhat Important
3 = Medium Importance
4 = Very Important

If you are not interested in scenario co-benefits, there is no need to modify default selections in this step.

The default selection for importance factors is set to 2 (Somewhat Important) so that the importance of all indicators is considered equal. If you do not identify co-benefit indicators that are more important than others, the default selections should be kept in place.

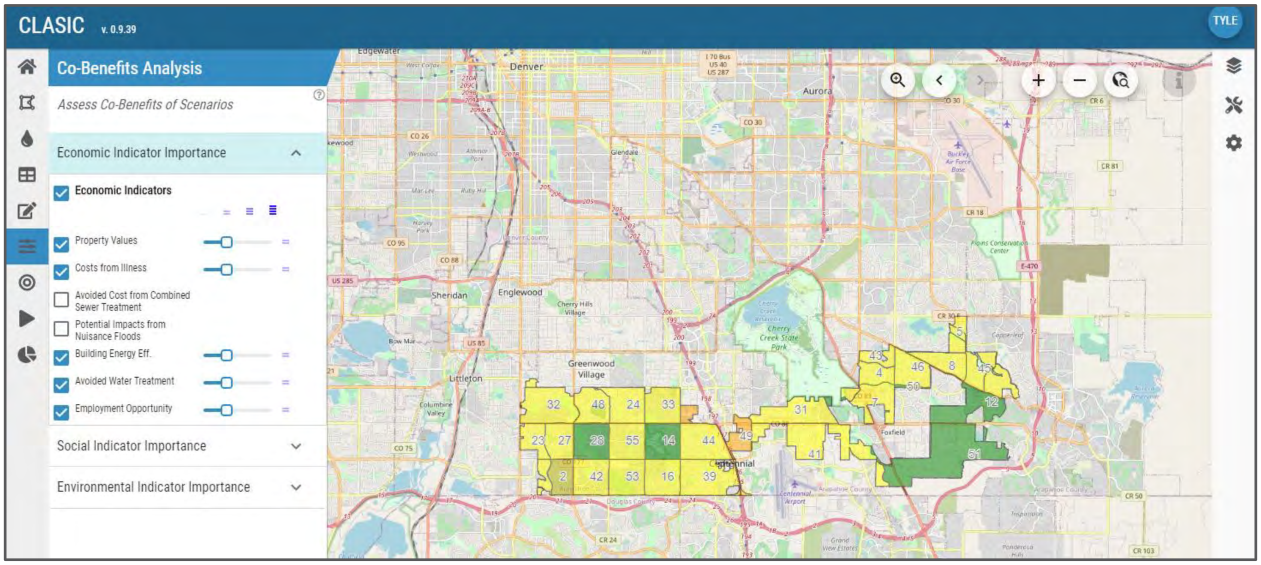


Figure 14: Selection of importance factors for co-benefit indicators

Note that the co-benefits analysis does not include lifecycle cost or hydrologic performance directly since those are considered direct benefits/consequences of the scenarios. The intent is that co-benefits are compared alongside of lifecycle cost and performance of scenarios.

The methodology for estimation of co-benefits is summarized in Appendix B.

◎ SET TARGETS

If there are water quality, hydrologic, or cost targets that scenarios should meet, those should be entered here. If you would like to view results for all scenarios whether targets are met or not, no inputs are required here. Enter values for contaminants where targets are desired.

1. *Pollutant Reduction*: Enter desired reduction of contaminant loads as percent change from the baseline scenario to assess whether addition of technologies results in desired TMDLs for total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN), or fecal indicator bacteria (FIB). The user should only enter values for contaminants where targets are desired.
2. *Runoff Reduction (%)*: Enter desired reduction of runoff volume as percent change from the baseline scenario to assess whether addition of technologies will result in targets met for runoff volume reduction.
3. *Total Cost ($)*: Enter a total life cycle cost for the period that should not be exceeded.
4. *Annual Average ($)*: Enter an average annual cost for the life cycle period that should not be exceeded.

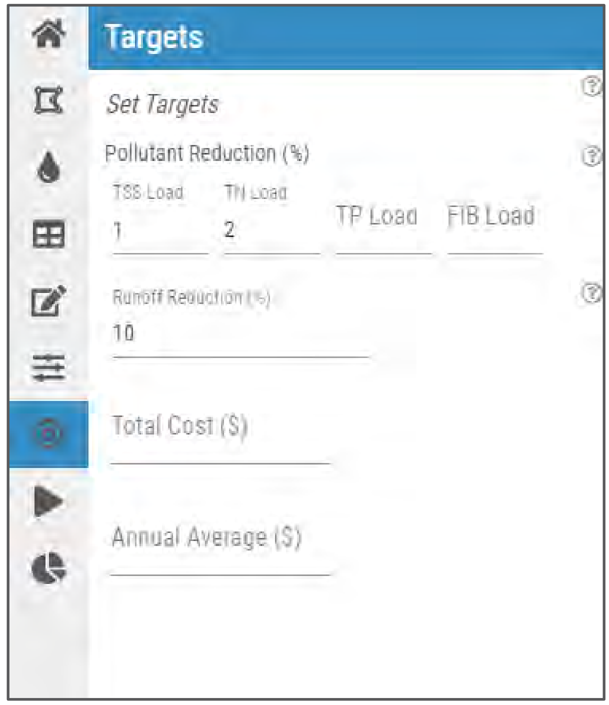


Figure 15: Setting pollutant removal and costs targets

Run CLASIC

Click Run. This will run the tool for any scenario that has yet to be ran or for any scenario that has been modified since the last run.

Note: A typical run may take 5 minutes. Run time can be shortened by decreasing the duration of weather data used or decreasing the number of subunits or technologies added to the project.

View Results

1. Select the scenarios for which you would like to view results. You can view results from up to 3 scenarios at a time. (Figure 16).
2. The first tab includes a summary of lifecycle cost, performance, and co-benefits (Figure 16). For more outputs in any of these three categories, click on the tab for which you would like to view more outputs. The approach for lifecycle cost estimates is summarized in Appendix C. The question mark help button by each graphic provides guidance to interpret results. An explanation of each graphical output is also included in Appendix D.
3. If you would like a summary of results for all scenarios run, click on the pdf button (see figure above, top right) to generate a pdf report.

- Check the figures in the generated pdf file. The figures sometimes get cutoff horizontally. If this happens, print pdf in landscape orientation instead of portrait.

4. If you would like to download data from any specific chart shown in the graphical outputs, click on the icon at the top right of the graphic to select the format (see figure above).

If you would like to view more scenarios of technologies, climate, or land use, build more scenarios. You can continue to build and view results for scenarios.

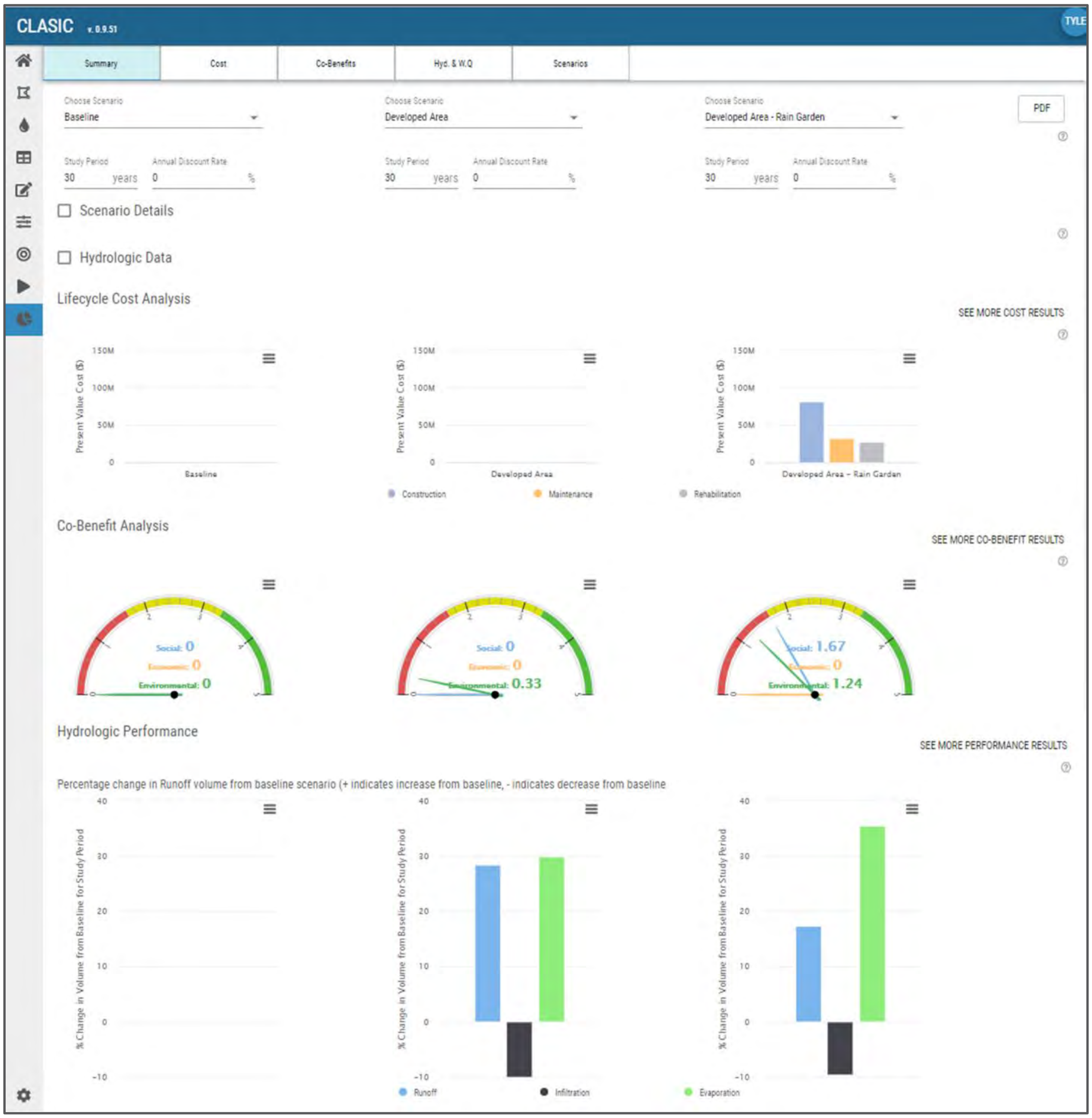


Figure 16: Graphical outputs summarizing performance for cost, co-benefits and hydrology

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APPENDIX A: SPECIFICATIONS FOR TECHNOLOGY PARAMETERS

TECHNOLOGY PARAMETERS AND ASSUMPTIONS

Ten technologies are available to users within the CLASIC tool, seven of which are volume-based: rain gardens, sand filters, infiltration trenches, dry detention basins, wet ponds, rainwater harvesting, and storage tanks/tunnels. Three area-based technologies are also available: vegetated buffers, green roofs, and permeable pavement. A summary of each technology and the parameters required are presented below. In order to account for the variation of design of technologies, users of the CLASIC tool will be able to select variable sizes (small, medium, large) and add or remove different components (e.g., vegetation, underdrain, impermeable liner) that are relevant to each technology.

Rain Garden

A rain garden is a bioretention stormwater management practice where a shallow basin is used to capture stormwater runoff. Vegetation and layers of different mulch, soils and aggregates are used to mimic the ecological functions of a natural landscape. Rain gardens capture, filter, treat and infiltrate or transpire stormwater (NGICP, 2019).

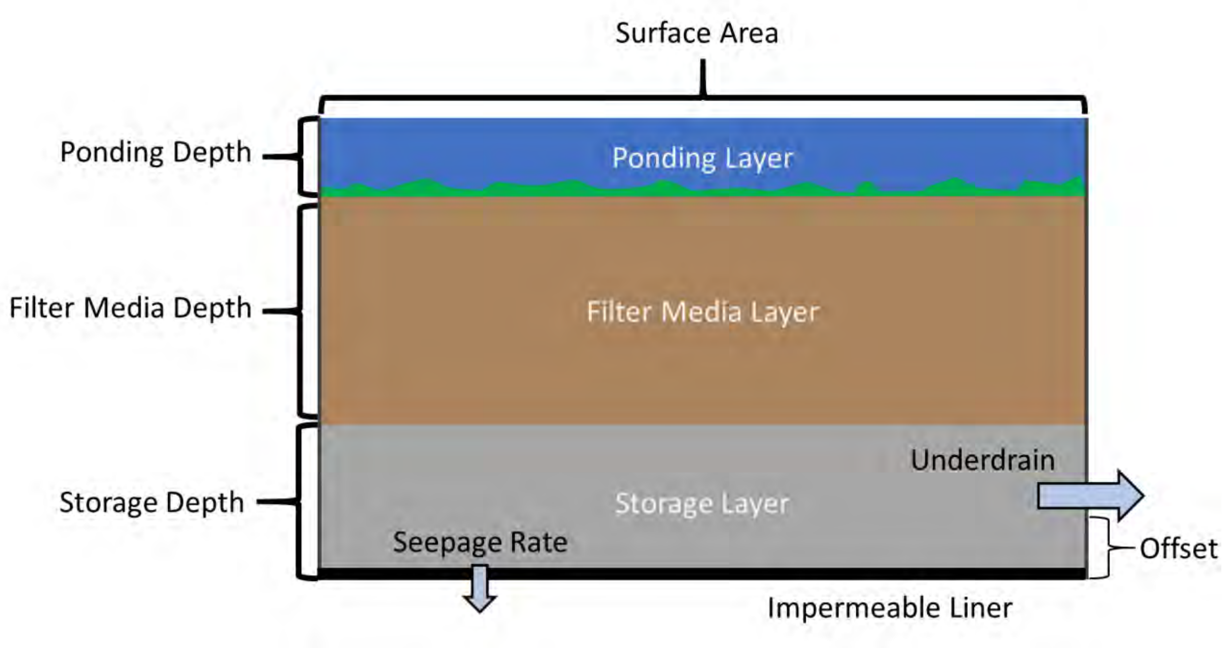


Figure A.1: Diagram of a rain garden as it is represented in SWMM module of CLASIC.

Figure A.1 illustrates how rain gardens are modeled within the CLASIC tool. Users can change several parameters of rain gardens that significantly affect the hydrologic performance, cost of the technology, and co-benefits. However, to reduce the number of inputs required from the user, some parameters have been assumed and are not editable. The parameters that are available to be changed by the user and the parameters that are assumed for modeling are described below.

Options for Modifying Design Parameter Defaults

Rain Garden Class: Choose from small, medium, or large, changing the class of the technology changes the surface area as well as defaults for the parameters below including ponding depth, filter media depth, and number of trees. Table A.1 shows the default parameters that are assumed for rain gardens based on the rain garden class selected. Default parameters were also used for estimating the cost of the technology even if the user modified some of the parameters in the technology interface, user modification only affected hydrologic performance.

Table A.1: Rain garden parameters that were used as defaults and for cost calculation based on class

Rain Garden Dimensions	Small	Medium	Large
Surface Area (sq. ft)	100	1000	10,000
Ponding Depth (in)	6	12	12
Filter Media Depth (in)	18	18	24
Storage Layer Depth (in)	0 or 12		
Side Slope	Assume vertical		
Underdrain Parameters			
Length of Pipe (ft):	15	95	600
Size of Underdrain (in):	4	4	6
Numbers of Risers:	1	4	10
Liner Parameters			
Material (sq. ft)	220	1443	11,600
Boundary Wall to Fasten Liner (ft)	40	126	400
Vegetation Parameters			
# of Trees	1	2	3

Ponding Depth: Ponding depth sets the available storage depth above the surface of the technology. Ponding depth can range from 3-18 inches. Adjusting the ponding depth will affect the volume of water captured by a single technology which changes the number of technologies required.

Filter Media Depth: Filter media depth sets the thickness or depth of the filter media layer. Filter media depth can range from 12-36 inches. Adjusting the filter media depth will affect the volume of water captured by a single technology which changes the number of technologies required.

Includes Impermeable Liner: An impermeable liner may be used to prevent seepage to native soils. Liners are often used when next to building foundations or to prevent groundwater interactions. If the impermeable liner is turned on, the seepage rate is set to zero and an underdrain must be used.

Seepage Rate: Seepage rate is the rate which water will infiltrate into the native soils. Higher seepage rates will result in more runoff being reduced by the technology. Seepage rates may range from 0-5 in/hr.

Includes Underdrain: Underdrains provide drainage for the technology when soils beneath the technology drain poorly or when an impermeable liner is used. When an underdrain is not used, all runoff that enters the technology will either evapotranspire or infiltrate into native soils.

Drain Time: Drain time is the number of hours required to empty the full technology completely through the underdrain. Drain time may range between 12-72 hours.

Offset Height: Offset height sets an offset between the bottom of the storage layer of the rain garden and the underdrain. Offset heights may range between 0-12 inches. Increasing the offset height will increase the volume of runoff infiltrated. If an impermeable liner is used, then the offset should be set to zero.

Vegetation Type: Choose from grass or diverse to define the vegetation which covers the technology area. If grass is selected, then vegetation installation type and mowing regime can be adjusted. If diverse is selected it is assumed that non-grass plants are installed. With diverse, a user can select the range of the number of species and percent flowering vegetation, which affect co-benefits.

Vegetation Installation Type: Vegetation installation type defines the method of installation used to install the grass vegetation that will cover the surface of the technology. Choose from three methods available for installation, seed, sod, and plug with seed being the least expensive and plug being the most expensive.

Requires Routine Mowing: Selecting this option means that the grass is in an area or is of a species that requires regular mowing. Adding routine mowing to a technology increases the maintenance cost of the technology.

Mowing Season: Define the number of months mowing is required.

Number of Species: Define the number species planted in the technology. Increasing the number of species results in additional co-benefits.

Percentage Flowering Vegetation: Define the percentage of vegetation that will occupy the surface of the technology that contains a flowering species. Higher percentage of flowering species increases the co-benefits provided by the technology.

Includes Irrigation System: Selecting this option means that the grass is in an area or is of a species that requires regular irrigation. Adding irrigation to a technology increases cost of the technology.

Irrigation Season: Define the number of months irrigation is required.

Includes Tree(s): Selecting this option means that trees will be included with the technology. Based on the size of the technology the number of trees is assumed. Including trees increases the co-benefits and costs of the technology. Species and maturity of tree can be adjusted in "Advanced Scenario Options".

Technology Placement: Technologies can either be placed in surrounding pervious area provided by traditional landscaping or when pervious area is not available, will be placed in captured impervious area.

Percent Impervious Area Captured: The percent of impervious area for which runoff drains to the technology with the parameters selected above. The total percent impervious area captured for all technologies applied in a subunit cannot exceed 100%.

Depth to Capture: Precipitation depth assumed over the captured impervious area to inform the design of the technology and the number of technologies needed. Depth to capture may range from 0.1 – 10 inches.

Technology Calculations

Once a technology is defined, the total volume required to be captured, volume captured per technology, number of technologies, and total surface area for the technology are all calculated. The volume required to be captured is determined by the subunit area, percent imperviousness of the subunit, percent impervious area captured, and depth to capture as seen by Equation .

Equation A.1

$$Volume\ Capacity\ Required\ (ft^3) = Subunit\ area\ (acres) * \%\ Impervious * \%\ Impervious\ Area\ Captured * Depth\ to\ Capture\ (in) * \frac{43560}{12}$$

Based on the user selections for the technology, a unit capacity can be calculated using Equation . For rain gardens, the unit capacity was determined based on the surface area of each technology and the depth available to store water in the ponding layer and filter media layer. For the filter media a porosity of 0.4 was assumed to calculate the capacity of each technology.

Equation A.2

$$Volume\ per\ Technology\ (ft^3) = Surface\ Area\ (ft^2) * \frac{Ponding\ Depth\ (in) + 0.4 * Filter\ Media\ Depth\ (in)}{12}$$

After the total volume required to be captured was determined as well as the unit capacity each technology could manage, the total number of technologies needed to provide the necessary volume to be captured was calculated using Equation .

Equation A.3

$$Number\ of\ Technolgies = Roundup\left[\frac{Volume\ Capacity\ Required}{Volume\ per\ Technology}\right]$$

After the number of technologies is determined, the total area required to provide the necessary captured volume is determined using Equation . The technology area represents the pervious area that accepts the routed stormwater runoff from the impervious area it is determined to treat by the user.

Equation A.4:

$$Technology\ Area\ (acres) = \frac{\#\ of\ Technologies * Surface\ Area\ (ft^2)}{43560}$$

Based on these calculations, the number of technologies can be determined which influences cost as well as the total area of technologies which influences the hydrologic performance.

SWMM Parameters

Rain gardens are modeled using the LID bioretention module within SWMM. LID modules within SWMM use various layers with storage capacity combined with fluxes that represent different the stormwater practice. Within the bioretention module there are three different layers: ponding, filter media and storage. Figure A.1 (above) displays the various layers within the rain garden as well as the different processes that are modeled for how water can enter and exit each layer. Table A.2 displays the parameters used for the bioretention unit to model rain gardens in SWMM.

Table A.2: SWMM Technology parameters for bioretention unit to model rain gardens.

Ponding Layer	
Ponding Depth (inches)	User

Vegetation Volume Fraction	0.1
Surface Roughness (n)	-
Surface Slope (percent)	-
Filter Media Layer	
Filter Media Depth (inches)	User
Porosity	0.437
Field Capacity	0.105
Wilting Point	0.047
Conductivity (in/hr)	1.18
Conductivity Slope	50
Suction Head (in)	2.4
Storage Layer	
Thickness (in)	12
Void ratio	0.67
Seepage Rate (in/hr)	User
Clogging Factor	-
Drain Parameters	
Flow Coefficient	$\frac{2 * \sqrt{D}}{Drain\ Time}$
Flow Exponent	0.5
Offset Height (in)	User

Sand Filter

A sand filter is a filtration stormwater management practice where a shallow basin is used to capture stormwater runoff. Layers of sand and aggregate are used to provide filtration of the stormwater runoff while better mimicking the ecological functions of a natural landscape. Sand filters capture, filter, and infiltrate stormwater (modified from NGICP, 2019).

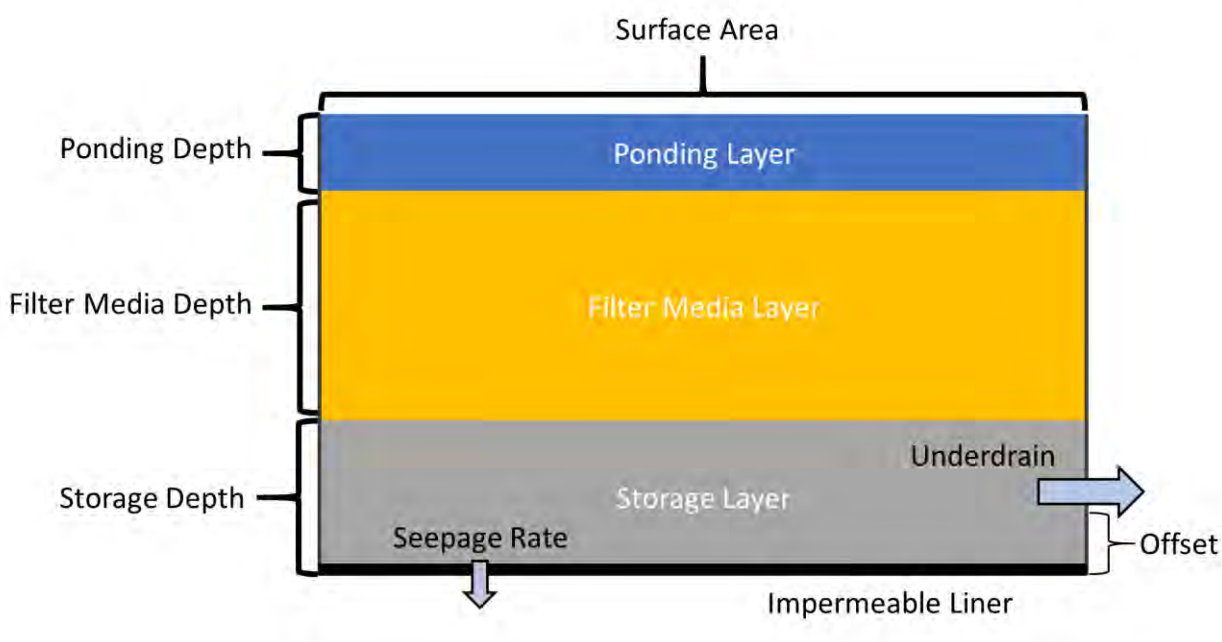


Figure A.2: Diagram of a sand filter as it is represented in SWMM module of CLASIC.

Figure A.2 displays a diagram of how sand filters are modeled within the CLASIC tool. The CLASIC tool allows users to change several parameters of sand filters that significantly affect the hydrologic performance, cost of the technology, and co-benefits. However, to reduce the number of inputs required from the user, some parameters have been assumed and are not editable by the user. The parameters that are available to be changed by the user and the parameters that are assumed for modeling are displayed below.

Options for Modifying Design Parameter Defaults

Sand Filter Class: Choose from small, medium, or large, changing the class of the technology changes the surface area as well as defaults for the parameters below including ponding depth and filter media depth. Table A.3 shows the default parameters that are assumed for sand filters based on the class selected. Default parameters were also used for estimating the cost of the technology even if the user modified some of the parameters in the technology interface, user modification only affected hydrologic performance.

Table A.3: Sand filter parameters that were used as defaults and for cost calculation based on class

Sand Filter Dimensions	Small	Medium	Large
Surface Area (sq. ft)	100	1000	10,000
Ponding Depth (in)	6	12	12
Filter Media Depth (in)	18	18	24

Storage Layer Depth (in)	0 or 12		
Side Slope	Assume vertical		
Underdrain Parameters			
Length of Pipe (ft):	15	95	600
Size of Underdrain (in):	4	4	6
Numbers of Risers:	1	4	10
Liner Parameters			
Material (sq. ft)	220	1443	11,600
Boundary Wall to Fasten Liner (ft)	40	126	400

Ponding Depth: Ponding depth sets the available storage depth above the surface of the technology. Ponding depth can range from 3-18 inches. Adjusting the ponding depth will affect the volume of water captured by a single technology which changes the number of technologies required.

Filter Media Depth: Filter media depth sets the thickness or depth of the filter media layer. Filter media depth can range from 12-36 inches. Adjusting the filter media depth will affect the volume of water captured by a single technology which changes the number of technologies required.

Includes Impermeable Liner: An impermeable liner may be used to prevent seepage to native soils. Liners are often used when next to building foundations or to prevent groundwater interactions. If the impermeable liner is turned on, the seepage rate is set to 0 and an underdrain must be used.

Seepage Rate: Seepage rate is the rate which water will infiltrate into the native soils. Higher seepage rates will result in more runoff being reduced by the technology. Seepage rates may range from 0-5 in/hr.

Includes Underdrain: Underdrains provide drainage for the technology when soils beneath the technology drain poorly or when an impermeable liner is used. When an underdrain is not used, all runoff that enters the technology will either evaporate or infiltrate into native soils.

Drain Time: Drain time is the number of hours required to empty the full technology completely through the underdrain. Drain time may range between 12-72 hours.

Offset Height: Offset height sets an offset between the bottom of the storage layer of the rain garden and the underdrain. Offset heights may range between 0-12 inches. Increasing the offset height will increase the volume of runoff infiltrated. If an impermeable liner is used, then the offset should be set to 0.

Technology Placement: Technologies can either be placed in surrounding pervious area provided by traditional landscaping or when pervious area is not available, will be placed in captured impervious area.

% Impervious Area Captured: The percent of impervious area for which runoff drains to the technology with the parameters selected above. The total % Impervious Area Captured for all technologies applied in a subunit cannot exceed 100%.

Depth to Capture: Precipitation depth assumed over the captured impervious area to inform the design of the technology and the number of technologies needed. Depth to capture may range from 0.1 – 10 inches.

Technology Calculations

Once a technology is defined, the total volume required to be captured, volume captured per technology, number of technologies, and total surface area for the technology are all calculated. The volume required to be captured is determined by the subunit area, percent imperviousness of the subunit, percent impervious area captured, and depth to capture as seen by Equation .

Based on the user selections for the sand filter, a unit capacity can be calculated using Equation . For sand filters, like rain gardens, the unit capacity was determined based on the surface area of each technology and the depth available to store water in the ponding layer and filter media layer. For the filter media a porosity of 0.4 was assumed to calculate the capacity of each technology.

After the total volume required to be captured was determined as well as the unit capacity each technology could manage, the total number of technologies needed to provide the necessary volume to be captured was calculated using Equation .

After the number of technologies is determined, the total area required to provide the necessary captured volume is determined using Equation . The technology area represents the pervious area that accepts the routed stormwater runoff from the impervious area it is determined to treat by the user.

SWMM Parameters

Sand filters are modeled using the LID bioretention module within SWMM. Within the bioretention module there are three different layers, the ponding layer, filter media layer, and storage layer. Figure A.2 (above) displays the various layers within the sand filter as well as the different processes that are modeled for how water can enter and exit each layer. Table A.4 illustrates the parameters that were used for the bioretention unit to model sand filters in SWMM.

Table A.4: SWMM Technology parameters for bioretention unit to model sand filters.

Ponding Layer	
Ponding Depth (inches)	User
Vegetation Volume Fraction	0.0
Surface Roughness (n)	-
Surface Slope (percent)	-
Filter Media Layer	
Filter Media Depth (inches)	User
Porosity	0.437
Field Capacity	0.062
Wilting Point	0.024
Conductivity (in/hr)	4.74
Conductivity Slope	48
Suction Head (in)	1.93
Storage Layer	
Thickness (in)	12
Void ratio	0.67
Seepage Rate (in/hr)	User
Clogging Factor	-
Drain Parameters	
Flow Coefficient	$\frac{2 * \sqrt{D}}{Drain\ Time}$
Flow Exponent	0.5
Offset Height (in)	User

Infiltration Trench

An infiltration trench is a type of volume reducing practice using a primarily underground infiltration structure. On the surface, an infiltration trench can be exposed to allow ponding or be covered with similar material as the surrounding surface (e.g., pavement or landscaping). An infiltration trench is composed of a trench, filled with stone or gravel, with an open bottom to allow for infiltration. Stormwater runoff flows through an inlet where it is stored in the empty spaces between the stones, and slowly infiltrating through the bottom of the trench. Once the capacity of this system is exceeded, stormwater will overflow to a stormwater sewer system (modified from NGICP, 2019).

Figure A.3 displays a diagram of how infiltration trenches are modeled within the CLASIC tool. The CLASIC tool allows users to change several parameters of infiltration trenches that significantly affect the hydrologic performance, cost of the technology, and co-benefits. However, to reduce the number of inputs required from the user, some parameters have been assumed and are not editable by the user. The parameters that are available to be changed by the user and the parameters that are assumed for modeling are displayed below.

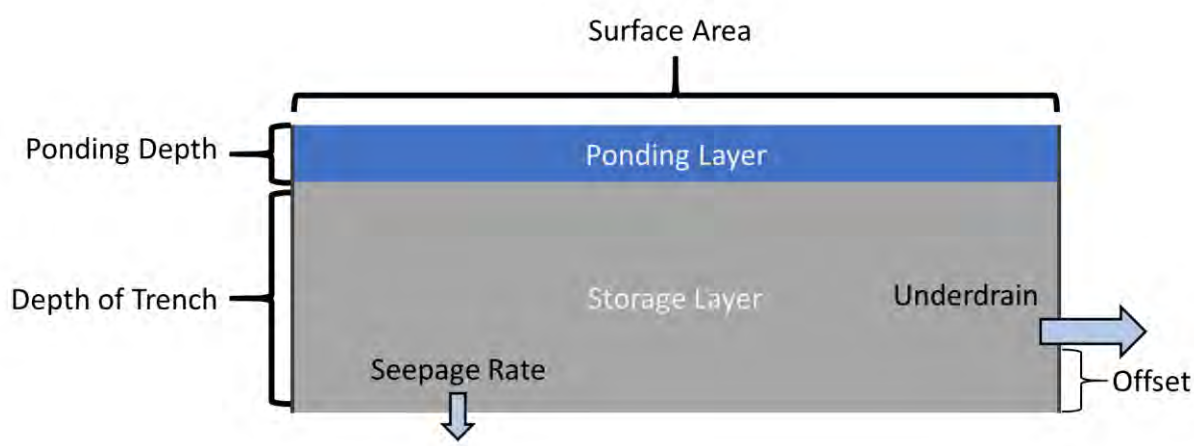


Figure A.3: Diagram of an infiltration trench as it is represented in SWMM module of CLASIC.

Options for Modifying Design Parameter Defaults

Infiltration Trench Class: Choose from small, medium, or large, changing the class of the technology changes the surface area of the technology. Table A.5 shows the default parameters that are assumed for infiltration trenches based on the class and depth selected. Default parameters were also used for estimating the cost of the technology even if the user modified some of the parameters in the technology interface, user modification only affected hydrologic performance.

Table A.5: Infiltration trench parameters that were used as defaults and for cost calculation based on class

Infiltration Trench Dimensions	Small	Medium	Large
Length (ft)	50	100	200
Width (ft)	3	6	10
Surface Area (sq. ft)	150	600	2000
Storage Depth Option	Deep/Shallow		
Storage Depth – Shallow (ft)	2		
Storage Depth – Deep (ft)	5		
Geotextile Area – Shallow (sq. ft)	362	1024	2840
Geotextile Area – Deep (sq. ft)	680	1660	4100
Underdrain Parameters			
Length of Pipe (ft)	50	100	200
Diameter of Underdrain (in):	4 (Shallow), 6 (Deep)		
Number of Risers:	1	1	2

Storage Depth Type: Choose from shallow or deep storage depth type. Shallow trenches range from 12-36 inches of storage depth where deep trenches range from 36-120 inches.

Depth of Trench: Depth of trench defines the actual storage depth available for the technology. Depth of trench depth can range from 12-36 inches for shallow trenches and 36-120 inches for deep trenches. Adjusting the depth of trench will affect the volume of water captured by a single technology which changes the number of technologies required.

Includes Surface Storage: Selecting this option allows for runoff to be stored above the surface of the technology as well as below the surface. When "Include Surface Storage" is selected the user will be asked to define the ponding depth.

Ponding Depth: Ponding depth sets the available storage depth above the surface of the technology. Ponding depth can range from 3-18 inches. Adjusting the ponding depth will affect the volume of water captured by a single technology which changes the number of technologies required.

Seepage Rate: Seepage rate is the rate which water will infiltrate into the native soils. Higher seepage rates will result in more runoff being reduced by the technology. Seepage rates may range from 0-5 in/hr.

Includes Underdrain: Underdrains provide drainage for the technology when soils beneath the technology drain poorly or when an impermeable liner is used. When an underdrain is not used, all runoff that enters the technology will either evaporate or infiltrate into native soils.

Drain Time: Drain time is the number of hours required to empty the full technology completely through the underdrain. Drain time may range between 12-72 hours.

Offset Height: Offset height sets an offset between the bottom of the storage layer of the rain garden and the underdrain. Offset heights may range between 0-12 inches. Increasing the offset height will increase the volume of runoff infiltrated. If an impermeable liner is used, then the offset should be set to 0.

Technology Placement: Technologies can either be placed in surrounding pervious area provided by traditional landscaping or when pervious area is not available, will be placed in captured impervious area.

Percent Impervious Area Captured: The percent of impervious area for which runoff drains to the technology with the parameters selected above. The total % Impervious Area Captured for all technologies applied in a subunit cannot exceed 100%.

Depth to Capture: Precipitation depth assumed over the captured impervious area to inform the design of the technology and the number of technologies needed. Depth to capture may range from 0.1 – 10 inches.

Technology Calculations

Once a technology is defined, the total volume required to be captured, volume captured per technology, number of technologies, and total surface area for the technology are all calculated. The volume required to be captured is determined by the subunit area, percent imperviousness of the subunit, percent impervious area captured, and depth to capture as seen by Equation .

Based on the user selections for the infiltration trench, a unit capacity can be calculated using Equation A.5. For infiltration trenches the unit capacity was determined based on the surface area of each technology and the depth available to store water in the ponding layer and storage layer. For the storage layer a porosity of 0.4 was assumed to calculate the capacity of each technology.

Equation A.5

$$Volume\ per\ Technology\ (ft^3) = Surface\ Area\ (ft^2) * \frac{Ponding\ Depth\ (in) + 0.4 * Depth\ of\ Trench\ (in)}{12}$$

After the total volume required to be captured was determined as well as the unit capacity each technology could manage, the total number of technologies needed to provide the necessary volume to be captured was calculated using Equation .

After the number of technologies is determined, the total area required to provide the necessary captured volume is determined using Equation . The technology area represents the pervious area that accepts the routed stormwater runoff from the impervious area it is determined to treat by the user.

SWMM Parameters

Infiltration trenches are modeled using the LID infiltration trench module within SWMM. Within the infiltration trench module there are two different layers, the ponding layer and storage layer. Figure A.3 (above) displays the various layers within the infiltration trench as well as the different processes that are modeled for how water can enter and exit each layer. Table A.6 illustrates the parameters that were used for the infiltration trench unit to model infiltration trenches in SWMM.

Table A.6: SWMM Technology parameters for infiltration trench unit to model infiltration trenches.

Ponding Layer	
Ponding Depth (inches)	User
Vegetation Volume Fraction	0.0
Surface Roughness (n)	-
Surface Slope (percent)	-
Storage Layer	
Thickness (in)	User
Void ratio	0.67
Seepage Rate (in/hr)	User
Clogging Factor	-
Drain Parameters	
Flow Coefficient	$\frac{2 * \sqrt{D}}{Drain\ Time}$
Flow Exponent	0.5

Offset Height (in)	User

Detention Basin

A detention basin is a shallow basin with a small slope between the inlet and the outlet structure. The outlet includes a low flow opening at the bottom of the pond that allows water collected in the basin to slowly drain out between storms and drainage events. Detention ponds are normally dry. Their purpose is only to temporarily store the water and slow the rate at which it is draining to local streams/rivers/lakes in order to help reduce chances of local flooding (NGICP, 2019).

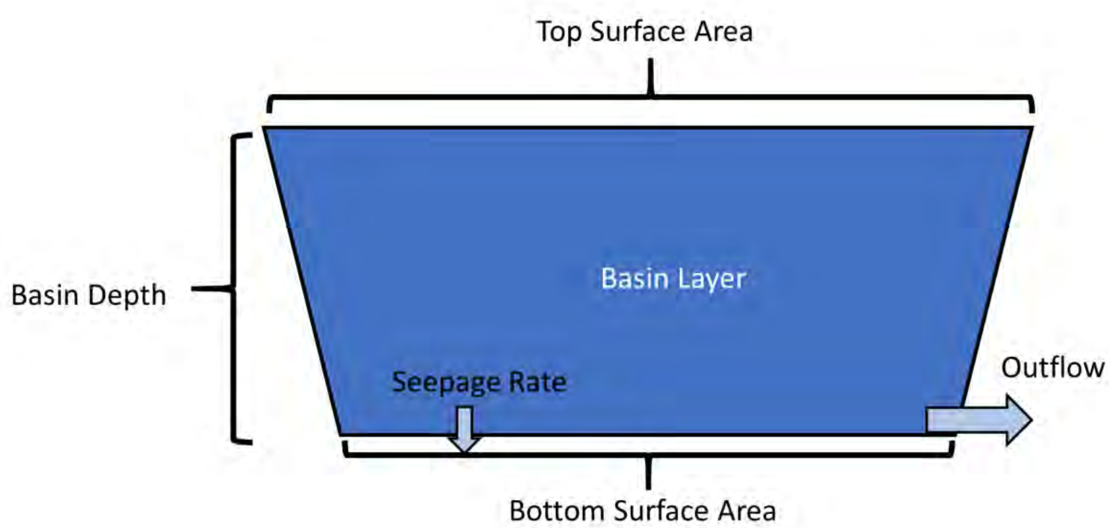


Figure A.4: Diagram of a detention basin as it is represented in SWMM.

Figure A.4 displays a diagram of how detention basins are modeled within the CLASIC tool. The CLASIC tool allows users to change several parameters of detention basins that significantly affect the hydrologic performance, cost of the technology, and co-benefits. However, to reduce the number of inputs required from the user, some parameters have been assumed and are not editable by the user. The parameters that are available to be changed by the user and the parameters that are assumed for modeling are displayed below.

Options for Modifying Design Parameter Defaults

Detention Basin Class: Choose from small, medium, or large, changing the class of the technology changes parameters corresponding to the size of the basin including basin depth, basin volume, bottom surface area and top surface area. Table A.7 shows the default parameters that are assumed for detention basins based on the class selected. Default parameters were also used for estimating the cost of the technology even if the user modified some of the parameters in the technology interface, user modification only affected hydrologic performance.

Forebay: Selecting this option includes a forebay for the technology. The size of the forebay is dependent on the technology class.

Trickle Channel: Selecting this option includes a trickle channel for the technology. The size and shape of the trickle channel is dependent on the technology class.

Micropool: Selecting this option includes a micropool for the technology. The size of the micropool is dependent on the technology class.

Seepage Rate: Seepage rate is the rate which water will infiltrate into the native soils. Higher seepage rates will result in more runoff being reduced by the technology. Seepage rates may range from 0-5 in/hr.

Table A.7: Detention basin parameters that were used as defaults and for cost calculation based on class

Detention Basin Dimensions	Small	Medium	Large
Bottom Width (ft)	50.0	100.0	200.0
Bottom Length (ft)	100.0	200.0	400.0
Bottom Area (sq. ft)	5000.0	20000.0	80000.0
Basin Depth (ft)	2.0	4.0	8.0
Side Slopes (H:V)	4	4	4
Top Width (ft)	66.0	132.0	264.0
Top Length (ft)	116.0	232.0	464.0
Top Area (sq. ft)	7656.0	30624.0	122496.0
Basin Volume (cu. ft)	12,500	100,000	805,000
Outlet Structure Dimensions (width x length x depth)	3’ x 3’ x 2'	4’ x 4’ x 4'	5’ x 5’ x 8'
Emergency Spillway Length (ft)	10	20	30
Maintenance Road (ft)	182.0	364.0	728.0
Vegetation Parameters			
Number of Trees	3	6	9
Forebay Parameters			

Forebay Depth (in)	6	12	18
Forebay Surface Area (sq. ft)	50	200	800
Trickle Channel Parameters			
Channel Length (ft)	150	300	600
Channel Width (ft)	2	3	5
Channel Shape	V-shaped	Flat bottom with curb	Flat bottom with curb
Micropool Parameters			
Micropool Dimensions (width x length x depth)	3′ x 4′ x 2′	4′ x 6′ x 2′	5′ x 6′ x 2.5′

Drain Time: Drain time is the number of hours required to empty the full technology completely through the underdrain. Drain time may range between 12-72 hours.

Vegetation Installation Type: Vegetation installation type defines the method of installation used to install the grass vegetation that will cover the surface of the technology. Choose from two methods available for installation, seed or sod; with seed being less expensive and sod being more expensive.

Requires Routine Mowing: Selecting this option means that the grass is in an area or is of a species that requires regular mowing. Adding routine mowing to a technology increases the maintenance cost of the technology.

Mowing Season: Define the number of months mowing is required.

Includes Irrigation System: Selecting this option means that the grass is in an area or is of a species that requires regular irrigation. Adding irrigation to a technology increases cost of the technology.

Irrigation Season: Define the number of months irrigation is required.

Includes Tree(s): Selecting this option means that trees will be included with the technology. Based on the size of the technology the number of trees is assumed. Including trees increases the co-benefits and costs of the technology. Species and maturity of tree can be adjusted in "Advanced Scenario Options".

Retrofit: Selecting this option means that an existing flood control basin will be retrofitted to include a water quality component. If a new basin will be constructed, then this box should not be checked. Specifying the technology is a retrofit decreases the overall cost of the basin.

Technology Placement: Technologies can either be placed in surrounding pervious area provided by traditional landscaping or when pervious area is not available, will be placed in captured impervious area.

% Impervious Area Captured: The percent of impervious area for which runoff drains to the technology with the parameters selected above. The total % Impervious Area Captured for all technologies applied in a subunit cannot exceed 100%.

Depth to Capture: Precipitation depth assumed over the captured impervious area to inform the design of the technology and the number of technologies needed. Depth to capture may range from 0.1 – 10 inches.

Technology Calculations

Once a technology is defined, the total volume required to be captured, volume captured per technology, number of technologies, and total surface area for the technology are all calculated. The volume required to be captured is determined by the subunit area, percent imperviousness of the subunit, percent impervious area captured, and depth to capture as seen by Equation .

Based on the user selections for the detention basin, a unit capacity is assumed. Small, medium, and large basins are assumed to have a storage capacity of 12,500, 100,000, and 805,000 cubic feet respectively. This volume is all stored in the ponding layer of the detention basin. Unlike other technologies, the volume capacity of detention basins was not editable by the user because of the sensitivity between size and shape of the basin and cost.

After the total volume required to be captured was determined as well as the unit capacity each technology could manage, the total number of technologies needed to provide the necessary volume to be captured was calculated using Equation .

After the number of technologies is determined, the total area required to provide the necessary captured volume is determined using Equation A.6. Due to the side slopes necessary for detention basins, the technology area was calculated based on the top surface area, which is the largest portion of the technology. The technology area represents the pervious area that accepts the routed stormwater runoff from the impervious area it is determined to treat by the user.

Equation A.6

$$Tech\ Area\ (acres) = \frac{\#\ of\ Technologies * Top\ Surface\ Area\ (ft^2)}{43560}$$

SWMM Parameters

Detention basins are modeled using the LID infiltration trench module within SWMM. Within the infiltration trench module there are two different layers, the ponding layer and storage layer. The infiltration trench module was used because it allows for a surface ponding layer that can be used to mimic the storage capacity of the detention basin while also providing a drain for the system and allowing for seepage. Figure A.4 (above) displays the various processes modeled for the detention basin.

The infiltration trench module was modified to reduce any storage capacity provided by the storage layer, while ensuring that drainage and seepage from the storage layer were accurate. In the SWMM LID module for infiltration trenches, the depth of the storage layer was found to influence the drainage and seepage of the storage layer specifically if it was set as a shallow layer. However, the deeper the storage layer, the more artificial storage capacity was provided. To accommodate for this, the void ratio of the storage layer was assumed to be very small 0.1. The 0.1 void ratio corresponds to a porosity of 0.09. Having a small porosity allowed for a limited amount of artificial storage capacity to be added to the technology even though a deeper, 12 inches, storage layer was used. In order to ensure the drain down time matched what was selected by the user, flow leaving the detention basin technology was set at a constant rate of defined by the total storage capacity provided by the technology divided by the drain down time and seepage was set by the user.

Another modification for detention basins included adjusting the LID area. For other technologies, subcatchment areas and the area representing the pervious area of the technology and LID areas are the same. However for detention basins, because of the side slopes, the subcatchment area was determined based on the top area of the basin, or the largest portion of the basin. If the top area was used for the LID area, with the same basin depth, then the basin would provide more storage volume then required. In order to make volumes match, the LID area was determined by dividing the total volume managed by the practice by the depth of the practice. Table A.8 displays the parameters that were used for the infiltration trench unit to model detention basins in SWMM.

Table A.8: SWMM Technology parameters for infiltration trench unit to model detention basins.

Area Characteristics	
Ponding Layer	
Ponding Depth (inches)	Basin Depth x 12 (in/ft)
Vegetation Volume Fraction	0.0
Surface Roughness (n)	-
Surface Slope (percent)	-
Storage Layer	

Thickness (in)	12
Void ratio	0.1
Seepage Rate (in/hr)	User
Clogging Factor	-
Drain Parameters	
Flow Coefficient	$\frac{\text{Basin Depth x } 12\ (\frac{\text{in}}{\text{ft}})}{Drain\ Time}$
Flow Exponent	0
Offset Height (in)	0

Wet Pond

A wet pond is a shallow basin with inlets and an outlet structure. The outlet includes a low flow opening located at a higher elevation on the outlet structure that controls the normal depth of the pond. Wet ponds contain water. During a rain or melting event, they temporarily store additional water and slowly release it through the low flow opening to local streams/rivers/lakes to help reduce chances of local flooding. Once the pond drains down to the normal pond elevation (the elevation of the low flow opening), the rest of the water stays in (is retained in) the pond (retention pond in NGICP, 2019).

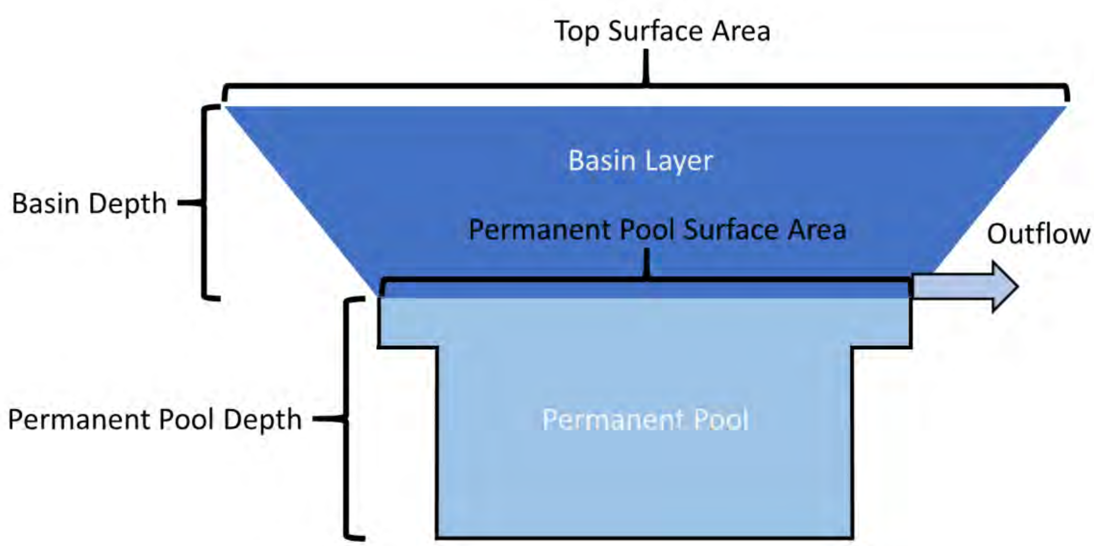


Figure A.5: Diagram of a wet pond as it is represented in SWMM module of CLASIC.

Figure A.5 displays a diagram of how wet ponds are modeled within the CLASIC tool. The CLASIC tool allows users to change several parameters of wet ponds that significantly affect the hydrologic performance, cost of the technology, and co-benefits. However, to reduce the number of inputs required from the user, some parameters have been assumed and are not editable by the user. The parameters that are available to be changed by the user and the parameters that are assumed for modeling are displayed below.

Options for Modifying Design Parameter Defaults

Wet Pond Size: Choose from small, medium, or large, changing the class of the technology changes parameters corresponding to the size of the basin including: basin depth, basin volume, top surface area permanent pool surface area, permanent pool depth, and permanent pool volume. Table A.9 shows the default parameters that are assumed for wet ponds based on the class selected. Default parameters were also used for estimating the cost of the technology even if the user modified some of the parameters in the technology interface, user modification only affected hydrologic performance.

Table A.9: Wet pond parameters that were used as defaults and for cost calculation based on class

Wet Pond Dimensions	Small	Medium	Large
Bottom Width (ft)	50.0	100.0	200.0
Bottom Length (ft)	100.0	200.0	400.0
Bottom Area (sq. ft)	5000.0	20000.0	80000.0
Basin Depth (ft)	2.0	4.0	8.0
Side Slopes (H:V)	4	4	4
Top Width (ft)	66.0	132.0	264.0
Top Length (ft)	116.0	232.0	464.0
Top Area (sq. ft)	7656.0	30624.0	122496.0
Basin Volume (cu. ft)	12,500	100,000	805,000
Outlet Structure Dimensions (width x length x depth)	3’ x 3’ x 2'	4’ x 4’ x 4'	5’ x 5’ x 8'
Emergency Spillway Length (ft)	10	20	30
Maintenance Road (ft)	182.0	364.0	728.0
Permanent Pool Parameters			

Pond depth (ft)	3	5	10
Pond Volume (cu. ft)	12, 700	91,000	757,000
Area of Deep Permanent Pool (sq. ft)	4,000	17,500	75,000
Forebay Parameters	50	200	800
Forebay Depth (in)			
Forebay Surface Area (sq. ft)	150	300	600

Forebay: Selecting this option includes a forebay for the technology. The size of the forebay is dependent on the technology class.

Drain Time: Drain time is the number of hours required to empty the full technology completely through the underdrain. Drain time may range between 12-72 hours.

Side Slope Vegetation Installation: Vegetation installation type defines the method of installation used to install the grass vegetation that will cover the side slopes of the technology. Choose from two methods available for installation, seed or sod; with seed being less expensive and sod being more expensive.

Requires Routine Mowing: Selecting this option means that the grass is in an area or is of a species that requires regular mowing. Adding routine mowing to a technology increases the maintenance cost of the technology.

Mowing Season: Define the number of months mowing is required.

Includes Irrigation System: Selecting this option means that the grass is in an area or is of a species that requires regular irrigation. Adding irrigation to a technology increases cost of the technology.

Irrigation Season: Define the number of months irrigation is required.

Retrofit: Selecting this option means that an existing flood control basin will be retrofitted to include a water quality component. If a new basin will be constructed, then this box should not be checked. Specifying the technology is a retrofit decreases the overall cost of the basin.

Technology Placement: Technologies can either be placed in surrounding pervious area provided by traditional landscaping or when pervious area is not available, will be placed in captured impervious area.

% Impervious Area Captured: The percent of impervious area for which runoff drains to the technology with the parameters selected above. The total % Impervious Area Captured for all technologies applied in a subunit cannot exceed 100%.

Depth to Capture: Precipitation depth assumed over the captured impervious area to inform the design of the technology and the number of technologies needed. Depth to capture may range from 0.1 – 10 inches.

Technology Calculations

Once a technology is defined, the total volume required to be captured, volume captured per technology, number of technologies, and total surface area for the technology are all calculated. The volume required to be captured is determined by the subunit area, percent imperviousness of the subunit, percent impervious area captured, and depth to capture as seen by Equation .

Based on the user selections for the wet pond, a unit capacity is assumed. Small, medium, and large basins are assumed to have additional storage capacity of 12,500, 100,000, and 805,000 cubic feet respectively. This volume is all stored in the ponding layer above the permanent pool of the wet pond. Unlike other technologies, the volume capacity of wet ponds was not editable by the user because of the sensitivity between size and shape of the basin and cost.

After the total volume required to be captured was determined as well as the unit capacity each technology could manage, the total number of technologies needed to provide the necessary volume to be captured was calculated using Equation .

After the number of technologies is determined, the total area required to provide the necessary captured volume is determined using Equation A.6. Due to the side slopes necessary for wet ponds, the technology area was calculated based on the top surface area, which is the largest portion of the technology. The technology area represents the pervious area that accepts the routed stormwater runoff from the impervious area it is determined to treat by the user.

SWMM Parameters

Wet ponds are modeled using the LID infiltration trench module within SWMM. For modeling wet ponds, the permanent pool was not considered. It was assumed that the permanent pool would be fed by groundwater or baseflow sources to preserve the permanent pool volume. Within the infiltration trench module there are two different layers, the ponding layer and storage layer. The infiltration trench module was used because it allows for a surface ponding layer that can be used to mimic the storage capacity of the wet pond while also providing a drain for the system. Figure A.5 (above) displays the various processes modeled for the wet pond.

The infiltration trench module was modified to reduce any storage capacity provided by the storage layer, while ensuring that drainage from the storage layer were accurate. In the SWMM LID module for infiltration trenches, the depth of the storage layer was found to influence the drainage and seepage of the storage layer specifically if it was set as a shallow layer. However, the deeper the storage layer, the more artificial storage capacity was provided. To accommodate for this, the void ratio of the storage layer was assumed to be very small 0.1. The 0.1 void ratio corresponds to a porosity of 0.09. Having a small porosity allowed for a limited amount of artificial storage capacity to be added to the technology even though a deeper, 12 inches, storage layer was used. In order to ensure the drain down time matched what was selected by the user, flow leaving the detention basin technology was set at a constant rate of defined by the total storage capacity provided by the technology divided by the drain down time. Because wet ponds displace water from the permanent pool, smaller drain down times can be used to achieve the displayed pollutant removal.

Another modification for wet ponds included adjusting the LID area. For other technologies, subcatchment areas and the area representing the pervious area of the technology and LID areas are the same. However for wet ponds, because of the side slopes of the basin, the subcatchment area was determined based on the top area of the basin, or the largest portion of the basin. If the top area was used for the LID area, with the same basin depth, then the basin would provide more storage volume then required. In order to make volumes match, the LID area was determined by dividing the total volume managed by the practice by the depth of the basin of the practice. Table A.10 displays the parameters that were used for the infiltration trench unit to model wet ponds in SWMM.

Stormwater Harvesting

Stormwater harvesting is the practice of collecting and temporarily storing stormwater in rain barrels or cisterns until it can be beneficially used for irrigation or some other non-potable use. (modified rainwater harvesting from NGICP, 2019).

Table A.10: SWMM Technology parameters for infiltration trench unit to model detention basins.

Area Characteristics	
Ponding Layer	
Ponding Depth (inches)	Basin Depth x 12 (in/ft)
Vegetation Volume Fraction	0.0
Surface Roughness (n)	-
Surface Slope (percent)	-
Storage Layer	
Thickness (in)	12
Void ratio	0.1
Seepage Rate (in/hr)	0.0

Clogging Factor	-
Drain Parameters	
Flow Coefficient	$\frac{\text{Basin Depth x 12 }(\frac{\text{in}}{\text{ft}})}{Drain\ Time}$
Flow Exponent	0
Offset Height (in)	0

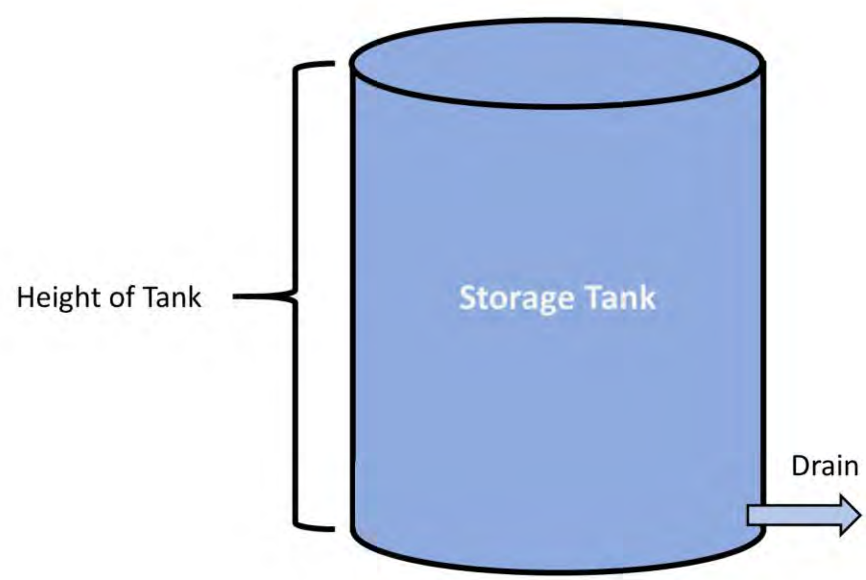


Figure A.6: Diagram of stormwater harvesting as it is represented in SWMM module of CLASIC.

Figure A.6 displays a diagram of how stormwater harvesting is modeled within the CLASIC tool. The CLASIC tool allows users to change several parameters of stormwater harvesting that significantly affect the hydrologic performance, cost of the technology, and co-benefits. However, to reduce the number of inputs required from the user, some parameters have been assumed and are not editable by the user. The parameters that are available to be changed by the user and the parameters that are assumed for modeling are displayed below.

Options for Modifying Design Parameter Defaults

Stormwater Harvesting Class: Choose from small, medium, or large, changing the class of the technology changes parameters corresponding to the size of storage tank and approximate height of the storage tank. Table A.11 shows the default parameters that are assumed for wet ponds based on the class selected. Default parameters were also used for estimating the cost of the technology even if the user modified some of the parameters in the technology interface, user modification only affected hydrologic performance.

Table A.11: Stormwater harvesting cistern parameters that were used as defaults and for cost calculation based on class

Stormwater Harvesting Cistern Dimensions	Small	Medium	Large
Capacity (gallons)	100	1000	10,000
Height of Tank (ft)	3	5	1
Area of Tank (sq. ft)	4.5	27.0	134
Water Source	Rooftop Runoff / General Runoff		
Tank Placement	Above Ground / Below Ground		
Pumping	True / False		
Usage Rate (gal/min)	0.035	0.347	3.472

Usage Rate: Usage rate controls the rate which stormwater drains from the storage tank. Usage rate should be in terms of an individual tank (based on the capacity of the selected size of tank). If time to drain tank is known, then simply divide the capacity of the individual tank by the time to drain the tank in days. Initial usage rates are calculated assuming a 2-day drain time.

Drain Delay: Drain delay is the number of hours after a storm before the tank will begin to empty. Drain delay may range between 0-72 hours.

Water Source: Defining the water source that enters the tank. A user can select between "General Stormwater" or "Rooftop Runoff". If "Rooftop Runoff" is selected, then the tank has flexibility in terms of placement and tank material. If "General Stormwater" is selected then the tank placement is assumed to be below ground, the tank material is assumed to be concrete and pumping is assumed to be necessary.

Stormwater Tank Placement: Choose between above ground or below ground. Tank placement affects the cost of the technology. If water source is set to "General Stormwater" then the tank placement is set to below ground. If the tank placement is set to below ground, then the tank material is set to concrete and pumping is assumed to be necessary.

Tank Material: Choose between concrete or plastic. Tank material affects the cost of the technology. If the tank placement is set to below ground, then the tank material is set to concrete.

Includes Pumping: Selecting this option means that pumping will be required for draining the system and is added to the cost of the technology.

Percent Impervious Area Captured: The percent of impervious area for which runoff drains to the technology with the parameters selected above. The total % Impervious Area Captured for all technologies applied in a subunit cannot exceed 100%.

Depth to Capture: Precipitation depth assumed over the captured impervious area to inform the design of the technology and the number of technologies needed. Depth to capture may range from 0.1 – 10 inches.

Technology Calculations

Once a technology is defined, the total volume required to be captured, volume captured per technology, number of technologies, and total surface area for the technology are all calculated. The volume required to be captured is determined by the subunit area, percent imperviousness of the subunit, percent impervious area captured, and depth to capture as seen by Equation .

Based on user selections for the stormwater harvesting, a unit capacity can be calculated using Equation A.7. For stormwater harvesting the unit capacity was set based on the class of stormwater harvesting selected by the user. The capacities for small, medium and large stormwater harvesting cisterns were set at 100, 1,000, and 10,000 gallons respectively. Equation A.7 simply converts the cistern capacity to cubic feet instead of gallons.

Equation A.7

$$Volume\ per\ Technology\ (ft^3) = \frac{Capacity(gal)}{7.481}$$

After the total volume required to be captured was determined as well as the unit capacity each technology could manage, the total number of technologies needed to provide the necessary volume to be captured was calculated using Equation .

After the number of technologies is determined, the total technology area required to provide the necessary captured volume is determined using Equation A.8. The calculated area is used as the area that contains the technology which accepts the routed stormwater runoff from the captured impervious area. For stormwater harvesting the area for the technology is assumed to come from the captured impervious area. The technology area is used for the subcatchment area and the LID usage area.

Equation A.8

$$Technology\ Area\ (acres) = \frac{\#\ of\ Technologies * \left(\frac{Capacity(gal)}{7.481 * Height\ of\ Tank}\right)}{43560}$$

SWMM Parameters

Stormwater harvesting cisterns are modeled using the LID rain barrel module within SWMM. LID modules within SWMM use various layers with storage capacity combined with fluxes that represent different the stormwater practice. Within the rain barrel module there is a single layer, the storage layer. Figure A.6 (above) displays the layer and components within the stormwater harvesting tank as well as the different processes that are modeled for how water can enter and exit the layer. In order to determine the drain down parameters for the system, the usage rate was collected from the user. The usage rate (gal/day) was used to determine the drain down time for the full tank by dividing the capacity of the tank by the usage rate. For the rain barrel LID module, the flow coefficient was calculated by dividing the depth or height of tank by the drain down time. Table A.12 illustrates the parameters that were used for the rain barrel unit to model stormwater harvesting in SWMM.

Table A.12: SWMM Technology parameters for rain barrel unit to model stormwater harvesting cisterns.

Storage Layer	
Height of tank (inches)	User (36, 60, or 120)
Drain Delay (hr)	User
Drain Parameters	
Flow Coefficient	$\frac{\left(\text{Height of Tank} * 12\left(\frac{\text{in}}{\text{hr}}\right)\right)}{\frac{Capacity}{Usage\ Rate} * 24\left(\frac{hr}{day}\right)}$
Flow Exponent	0
Offset Height (in)	User

Storage Vault

A storage vault is used for collecting and temporarily storing stormwater in large, underground structures until it can be drained. Storage vaults are typically used to increase the capacity of combined sewer systems.

Figure A.7 displays a diagram of how storage vaults are modeled within the CLASIC tool. The CLASIC tool allows users to change several parameters of storage vaults that significantly affect

Figure A.7: Diagram of a storage vault/tank as it is represented in SWMM module of CLASIC.

the hydrologic performance, cost of the technology, and co-benefits. However, to reduce the number of inputs required from the user, some parameters have been assumed and are not editable by the user. The parameters that are available to be changed by the user and the parameters that are assumed for modeling are displayed below.

Options for Modifying Design Parameter Defaults

Stormwater Tank Size: Choose from small, medium, or large, changing the class of the technology changes parameters corresponding to the capacity of storage vault. Table A.13 shows the default parameters that are assumed for storage vaults based on the class selected. Default parameters were also used for estimating the cost of the technology even if the user modified some of the parameters in the technology interface, user modification only affected hydrologic performance.

Table A.13: Stormwater harvesting cistern parameters that were used as defaults and for cost calculation based on class

Storage Vaults/Tunnel Dimensions	Small	Medium	Large
Capacity (million gallons)	0.1	0.5	1.0
Height of Tunnel (ft)	10	20	30
Length of Tunnel (ft)	200		
Pumping	True / False		
Assumed Days to Empty Tank	2		
Pumping Rate (gal/min)	40	165	365

Days to Empty Tank: Days to empty tank is the number of days required to fully drain the tank. Days to empty tank may range between 0.5-10 days and is defaulted to be 2 days.

Drain Delay: Drain delay is the number of hours after a storm before the tank will begin to empty. Drain delay may range between 0-72 hours.

Includes Pumping: Selecting this option means that pumping will be required for draining the system and is added to the cost of the technology.

% Impervious Area Captured: The percent of impervious area for which runoff drains to the technology with the parameters selected above. The total % Impervious Area Captured for all technologies applied in a subunit cannot exceed 100%.

Depth to Capture: Precipitation depth assumed over the captured impervious area to inform the design of the technology and the number of technologies needed. Depth to capture may range from 0.1 – 10 inches.

Technology Calculations

Once a technology is defined, the total volume required to be captured, volume captured per technology, number of technologies, and total surface area for the technology are all calculated. The volume required to be captured is determined by the subunit area, percent imperviousness of the subunit, percent impervious area captured, and depth to capture as seen by Equation .

Based on the user selections for the storage vaults, a unit capacity can be calculated using Equation A.7. For storage vaults the unit capacity was set based on the class of storage vaults selected by the user. The capacities for small, medium and large storage vaults were set at 0.1, 0.5, and 1.0 million gallons respectively. Equation A.7 simply converts the vault capacity to cubic feet from gallons.

After the total volume required to be captured was determined as well as the unit capacity each technology could manage, the total number of technologies needed to provide the necessary volume to be captured was calculated using Equation .

After the number of technologies is determined, the total technology area required to provide the necessary captured volume is determined using Equation A.8. The calculated area is used as the area that contains the technology which accepts the routed stormwater runoff from the captured impervious area. For storage vaults, the area for the technology is assumed to come from the captured impervious area. The technology area is used for the subcatchment area and the LID usage area.

SWMM Parameters

Storage vaults are modeled using the LID rain barrel module within SWMM. LID modules within SWMM use various layers with storage capacity combined with fluxes that represent different the stormwater practice. Within the rain barrel module there is a single layer, the storage layer.

Figure A.7 (above) displays the layer and components within the storage vault as well as the different processes that are modeled for how water can enter and exit the layer. The drain down time for the full tank is provided by the user in terms of number of days to empty the tank, and the drain down time influences the flow coefficient. For the rain barrel LID module, the flow coefficient was calculated by dividing the depth or height of tank by the drain down time. Table A.14 illustrates the parameters that were used for the rain barrel unit to model storage vaults in SWMM.

Table A.14: SWMM Technology parameters for rain barrel unit to model storage vaults.

Storage Layer	
Height of tank (inches)	User (120, 240, or 360)
Drain Delay (hr)	User
Drain Parameters	
Flow Coefficient	$\frac{\left(\text{Height of Tank} * 12\left(\frac{\text{in}}{\text{hr}}\right)\right)}{Drain\ down\ time\ (days) * 24\left(\frac{hr}{day}\right)}$
Flow Exponent	0
Offset Height (in)	User

Disconnection

Disconnection is the practice of routing water from an impervious area and distributing across a pervious area. Disconnection is traditionally accomplished by routing rooftop downspouts onto lawns (downspout disconnection) or by using grass buffers or swales to capture runoff from an impervious surface (general disconnection).

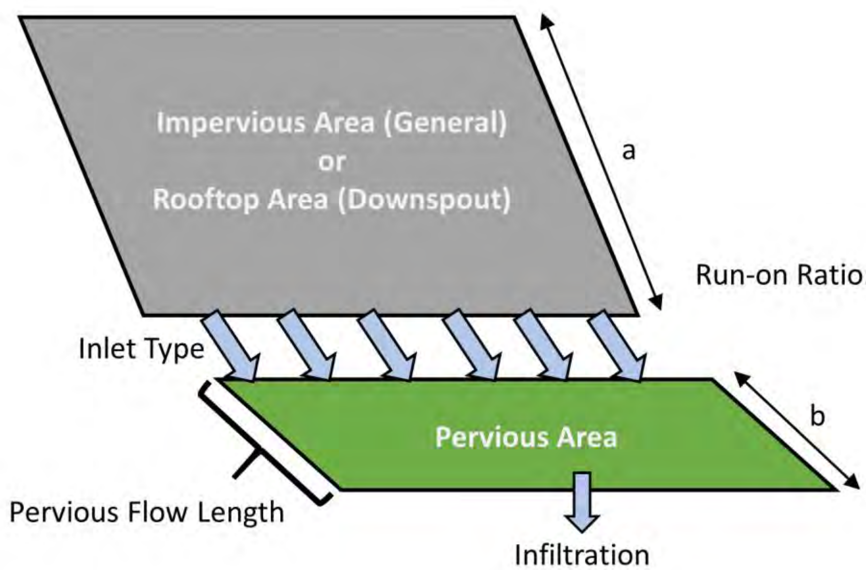


Figure A.8: Diagram of disconnection as it is represented in SWMM module in CLASIC.

Figure A.8 displays a diagram of how disconnection is modeled within the CLASIC tool. The CLASIC tool allows users to change several parameters regarding disconnection that significantly affect the hydrologic performance, cost of the technology, and co-benefits. However, to reduce the number of inputs required from the user, some parameters have been assumed and are not editable by the user. The parameters that are available to be changed by the user and the parameters that are assumed for modeling are displayed below.

Options for Modifying Design Parameter Defaults

Disconnection Type: Choose between two methods of disconnection. General disconnection routes a generic impervious area to generic pervious area using a specified inlet type. Downspout disconnection routes rooftop area onto pervious lawn area. If general disconnection is selected then the user will be able to adjust the inlet type between none, level spreader, or slotted curb. If downspout disconnection is selected than the amount of rooftop directed to each downspout is inputted to determine the approximate number of curbs to be disconnected. For both technologies, the amount of overland flow length is needed in order to correctly model the infiltration that occurs as a result of disconnection.

Inlet Type: Choose between three different inlet types: slotted curb, level spreader, or none. Slotted curb involves retrofitting existing curb or pouring new slotted curb to allow runoff to flow from the impervious to pervious section. A level spreader is a designed structure to evenly distribute runoff from the impervious to pervious section. For CLASIC cost estimations, it was assumed that the level spreader would be on average 150 ft. If a specific inlet type is not going to be used, but the impervious area will be graded to flow to the pervious as sheet flow conditions, then the "none" designation may be used. Inlet type does not affect the hydrologic effectiveness of the technology but is solely for cost estimation.

Retrofit Existing Curb: Selecting this option designates that existing curb will be modified or cut to provide an inlet to the pervious area, which has an associated cost. Alternatively pouring new slotted curb is not seen as an added project expense as curb typically necessary regardless if disconnection is accomplished.

Rooftop Area Per Downspout: Rooftop area per downspout is the amount of rooftop area which drains to an individual downspout. This parameter is used to define the number of downspouts that will be disconnected and can range from 100 – 1,000 square feet.

Flow Length of Pervious Area: The flow length of pervious area is the length water must flow across the pervious area and affects the amount of water that will be infiltrated by the pervious area. Longer flow lengths provide more infiltration. The flow length of pervious area may range from 5 – 200 feet.

Run-On Ratio: The ratio of impervious surfaces distributed to flow onto the receiving pervious area. Run-on ratio for disconnection may range from 1:1 – 10:1. The run-on ratio determines how much pervious area will be needed to achieve the disconnection for the selected imperviousness captured.

Adjust Pervious Infiltration: Selecting this option means that infiltration rates of the receiving pervious area may be set to parameters different from the sub-unit it occupies. Adjusting the pervious infiltration DOES NOT mean that soils are modified (i.e. not included in cost) but that the infiltration rates are naturally different and typically higher than the sub-unit.

Soil Type: Choose which soil type is representative of the receiving pervious area based on hydrologic soil group: A, B, C, D, other, custom. Selecting A, B, C, D, or other will use model default infiltration parameters for the corresponding soil. Selecting custom allows the infiltration rate to be set below.

Infiltration Rate: The infiltration rate is the custom rate for which runoff is predicted to infiltrate in inches per hour for the receiving pervious area. The infiltration rate may range from 0.01 – 5 inches per hours.

Technology Placement: Technologies can either be placed in surrounding pervious area provided by traditional landscaping or when pervious area is not available, will be placed in captured impervious area. If "Downspout Disconnection" is selected, then the area required for disconnection will be provided by the surrounding pervious area.

Percent Impervious Area Captured: The percent of impervious area for which runoff drains to the technology with the parameters selected above. The total % Impervious Area Captured for all technologies applied in a subunit cannot exceed 100%.

Technology Calculations

Disconnection is an area-based technology, therefore technology application is based solely on area and does not depend on captured volumes or technology volume capacity. The total impervious area required to be captured is found using Equation A.9. The area required to be captured is determined by the subunit area, percent imperviousness of the subunit, and percent impervious area captured.

Equation A.9

$$Impervious\ Area\ Captured\ (ft^2) = Subunit\ area\ (acres) * \%\ Impervious * \%\ Impervious\ Area\ Captured$$

Depending on the user selection of disconnection type between rooftop/downspout disconnection or general disconnection will determine how the pervious area required by the technology is provided. For downspout disconnection, users provide an average rooftop area per downspout, which is used to determine the number of downspouts needed to disconnect. The total impervious area captured along with the run-on ratio and the area used for technology placement determines how much technology area or pervious area is required. For downspout disconnection or general disconnection that uses surrounding pervious area to provide area for the technology Equation A.10 is used to determine the technology area. The technology area represents the pervious area that accepts the routed stormwater runoff from the impervious area it is determined to treat by the user.

Equation A.10

$$Technology\ Area\ (acres) = \frac{Captured\ Impervious\ Area\ (ft^2)}{Run - on\ Ratio *\ 43560}$$

If general disconnection is selected and the captured impervious area is selected as the technology placement area, then Equation A.11 is used to determine the technology area.

Equation A.11

$$Technology\ Area\ (acres) = \frac{Captured\ Impervious\ Area\ (ft^2)}{(Run - on\ Ratio + 1) *\ 43560}$$

SWMM Parameters

Disconnection is modeled differently in SWMM then other technologies in CLASIC. Other technologies in CLASIC use the LID modules within SWMM, but disconnection involves only routing an impervious area onto a pervious area. Figure A.10 (above) displays the how disconnection is modeled within in SWMM. Table A.15 illustrates the parameters that were used for modeling disconnection in SWMM. Because only subcatchments were used for modeling disconnection, Table A.15 displays how the subcatchment parameters were determined for the pervious area in CLASIC.

Table A.15: SWMM Technology parameters for pervious subcatchment to model sand filters.

Subcatchment Parameters	
Area (acres)	Equation A.10 or A.11
Width (ft)	$\frac{Area}{Flow\ length\ of\ pervious}$
Surface Roughness (n)	0.3
Depression Storage	0.2
Surface Slope (percent)	Sub-unit
Infiltration Parameters	
Maximum Infiltration (in/hr)	Sub-unit/User
Minimum Infiltration (in/hr)	Sub-unit/User
Decay Coefficient (1/hr)	Sub-unit/User

Permeable Pavement

Permeable pavement refers to a pavement system that includes a porous, load-bearing surface with an open-graded aggregate base below it that temporarily stores stormwater until it infiltrates into the underlying soils or drains to a controlled outlet (NGICP, 2019; Figure A.9).

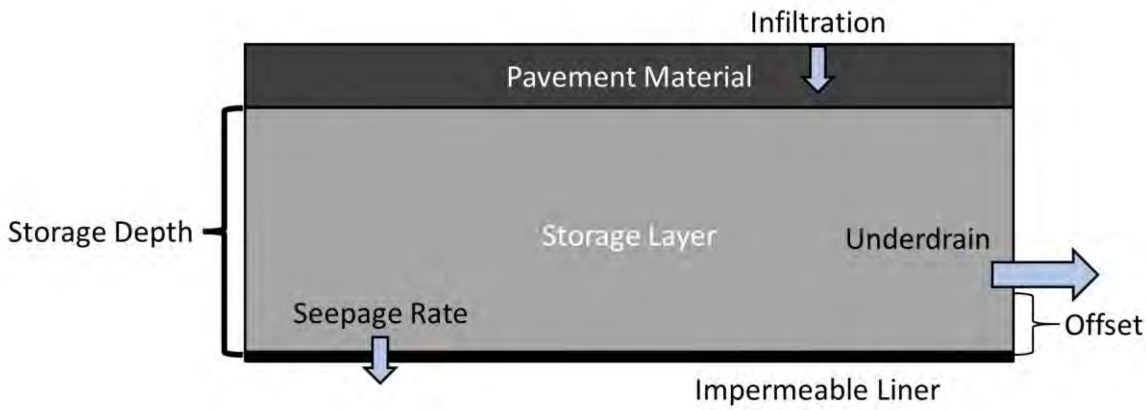


Figure A.9: Diagram of permeable pavement as it is represented in SWMM module of CLASIC.

The CLASIC tool allows users to change several parameters of permeable pavement that significantly affect the hydrologic performance, cost of the technology, and co-benefits. However, to reduce the number of inputs required from the user, some parameters have been assumed and are not editable by the user. The parameters that are available to be changed by the user and the parameters that are assumed for modeling are displayed below.

Table A.16 shows the default parameters that are assumed for permeable pavements. Costs were calculated assuming a continuous section of pavement that is half an acre and scaling to the number of half-acres of permeable pavement required to provide adequate treatment.

Table A.16: Permeable pavement parameters that were used as defaults and for cost calculations

Permeable Pavement Dimensions	
Pavement Area (sq. ft)	21,780
Pavement Thickness (in)	4
Storage Layer Thickness (in)	8, 12, 24, 36
Underdrain Parameters	
Length of Pipe (ft):	1,350
Size of Underdrain (in):	4
Numbers of Risers:	10
Liner Parameters	

Material (sq. ft)	22,665
Boundary Wall to Fasten Liner (ft)	590

Pavement Material: Choose between three types of permeable pavement, permeable interlocking concrete pavement (pavers), porous asphalt, or permeable concrete.

Includes Impermeable Liner: An impermeable liner may be used to prevent seepage to native soils. Liners are often used when next to building foundations or to prevent groundwater interactions. If the impermeable liner is turned on, the seepage rate is set to 0 and an underdrain must be used.

Seepage Rate: Seepage rate is the rate which water will infiltrate into the native soils. Higher seepage rates will result in more runoff being reduced by the technology. Seepage rates may range from 0-5 in/hr.

Includes Underdrain: Underdrains provide drainage for the technology when soils beneath the technology drain poorly or when an impermeable liner is used. When an underdrain is not used, all runoff that enters the technology will either evaporate or infiltrate into native soils.

Drain Time: Drain time is the number of hours required to empty the full technology completely through the underdrain. Drain time may range between 12-72 hours.

Offset Height: Offset height sets an offset between the bottom of the storage layer of the rain garden and the underdrain. Offset heights may range between 0-12 inches. Increasing the offset height will increase the volume of runoff infiltrated. If an impermeable liner is used then the offset should be set to 0.

Run-On Ratio: The ratio of traditional impervious surfaces distributed to flow onto the receiving permeable pavement. Run-on ratio will inform how much of the % Impervious Area Captured will become permeable pavement and the remaining impervious surfaces will be routed to the permeable pavement. A ratio of 0:1 indicates that entire captured impervious area will become permeable pavement and no additional runoff will be directed to it. A ratio of 1:1 indicates that half of the captured impervious area will become permeable pavement and the remaining half of traditional impervious surface will be directed to it. A ratio of 3:1 indicates that one quarter of the captured impervious area will become permeable pavement and the remaining three quarters of traditional impervious surface will be directed to it.

Percent Impervious Area Captured: The percent of impervious area for which runoff drains to the technology with the parameters selected above. The total % Impervious Area Captured for all technologies applied in a subunit cannot exceed 100%.

Depth to Capture: Precipitation depth assumed over the captured impervious area to inform the design of the technology. Depth to capture may range from 0.1 – 10 inches. For permeable pavements, because they are an area based technology which can also be used for flood control, the depth to capture only affects the storage depth and not the area of pavement. The technology area for permeable pavements is determined only by the run-on ratio and the amount of impervious area captured.

Storage Depth: Choose the depth of the storage layer available in inches. A depth is automatically populated based on the run-on ratio and the depth to capture to ensure adequate storage is provided. Changing this value will impact the hydrologic performance and cost of the permeable pavement. The storage depth can be set to 8, 12, 24, 36 inches, based on what is needed to capture the correct depth of imperviousness and the run-on ratio. Table A.17 shows the maximum depths of precipitation to capture for the various storage depths at different run-on ratios.

Table A.17: Maximum depths to capture for varying storage layer depths and run-on ratios for permeable pavements

Storage Depth	Run-On Ratio		
(in)	0:1	1:1	3:1
8	3.20	1.60	0.80
12	4.80	2.40	1.20
24	9.60	4.80	2.40
36	14.40	7.20	3.60

Technology Calculations

Permeable pavements are an area-based technology, therefore technology area is based solely on area and does not depend on captured volumes or technology volume capacity. Estimated captured volume did affect the storage as discussed above. The total impervious area required to be captured is found using Equation A.9. The area required to be captured is determined by the subunit area, percent imperviousness of the subunit, and percent impervious area captured.

The total impervious area captured along with the run-on ratio determines how much technology area or pervious area is required. For permeable pavements, it is defaulted that part or all of the impervious area captured is used to provide the area for the permeable pavements. Any remaining impervious area is then routed onto the permeable pavement. Equation A.11 is used to determine the technology area required to become permeable pavement. For example, a run-on ratio of 0:1 would result in all of the captured impervious area to become permeable pavement, but a run-on ratio of 1:1 would result in half of the captured impervious area becoming permeable pavement.

SWMM Parameters

Permeable pavements are LID permeable pavement module within SWMM. LID modules within SWMM use various layers with storage capacity combined with fluxes that represent different the stormwater practice. Within the permeable pavement module there are four different layers, the surface layer, pavement layer, filter media layer, and storage layer. CLASIC does not use all four layers for modeling of permeable pavements but only uses the pavement and storage layers. Figure A.9 (above) displays the various layers that are used to model permeable pavements as well as the different processes that are modeled for how water can enter and exit each layer. Table 5.23 illustrates the parameters that were used for the permeable pavement unit in SWMM.

Table A.18: SWMM Technology parameters for permeable pavement unit

Surface Layer	
Ponding Depth (inches)	0
Vegetation Volume Fraction	0.0
Surface Roughness (n)	0.1
Surface Slope (percent)	1.0
Pavement Layer	
Thickness (in)	4
Void Ratio	0.21 or 0.12 for pavers
Impervious Surface Fraction*	0
Permeability (in/hr)*	10
Clogging Factor	0
Regeneration Interval (days)^	0
Regeneration Fraction ^	0
Filter Media Layer	
Filter Media Depth (inches)	0
Porosity	0.437

Field Capacity	0.062
Wilting Point	0.024
Conductivity (in/hr)	4.74
Conductivity Slope	48
Suction Head (in)	1.93
Storage Layer	
Thickness (in)	User
Void ratio	0.67
Seepage Rate (in/hr)	User
Clogging Factor	0
Drain Parameters	
Flow Coefficient	$\frac{2*\sqrt{D}}{Drain\,Time}$
Flow Exponent	0.5
Offset Height (in)	User
* All pavements were assumed to be continuous surface, even permeable pavers. However, all infiltration rates were used as an average infiltration factoring in any impervious surfaces present in the pavement system	
^Pavement regeneration was not used for CLASIC	

Green Roof

A green roof is a roof of a building that is partially or completely covered with growing media and vegetation on top of a waterproof roof membrane. Rainwater falling on the rooftop is captured and stored in the media until it is used by the plants or it evaporates (NGICP, 2019).

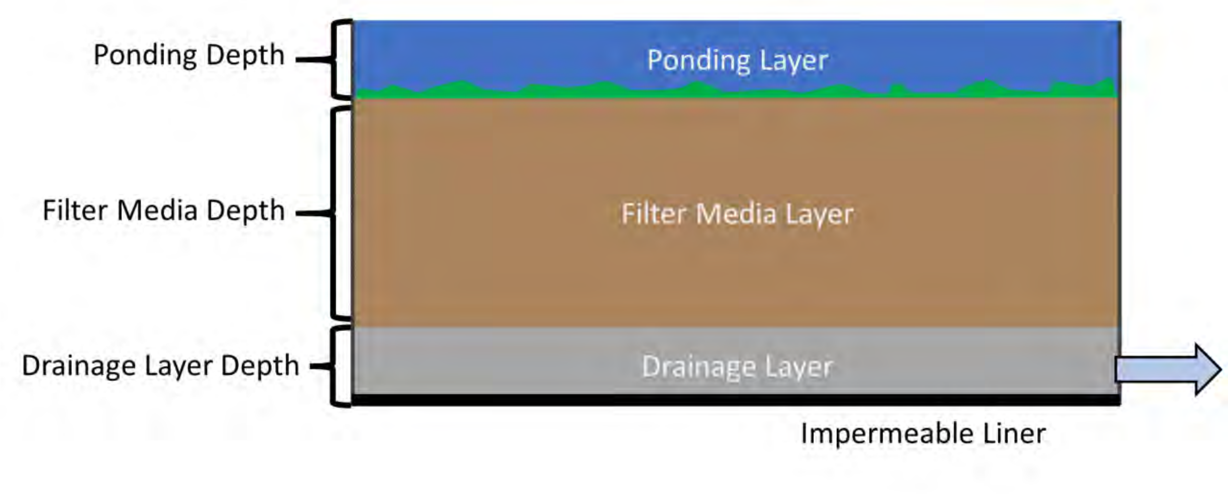


Figure A.10: Diagram of a green roof as it is represented in SWMM module of CLASIC.

Figure A.10 displays a diagram of how green roofs are modeled within the CLASIC tool. The CLASIC tool allows users to change several parameters of green roofs that significantly affect the hydrologic performance, cost of the technology, and co-benefits. However, to reduce the number of inputs required from the user, some parameters have been assumed and are not editable by the user. The parameters that are available to be changed by the user and the parameters that are assumed for modeling are displayed below.

Options for Modifying Design Parameter Defaults

Green Roof Class: Choose between two types of green roofs: extensive or intensive. Extensive roofs are shallower and require less structural support then intensive roofs. Table A.19 shows the default parameters that are assumed for green roofs based on the type selected. Default parameters were also used for estimating the cost of the technology even if the user modified some of the parameters in the technology interface, user modification only affected hydrologic performance. Costs were calculated assuming a continuous section of green roof of 2,178 or 5% of an acre and scaling that value to a per acre cost by multiplying by 20.

Table A.19: Green roof parameters that were used as defaults and for cost calculation based on type

Green Roof Dimensions	Extensive	Intensive
Installation Type:	Modular/Custom	Custom
Surface Area (sq. ft)	2178	
Width (ft):	33	

Length (ft):	66	
Perimeter (ft):	200	
Ponding Depth:	0	
Filter Media Depth (in)	4	8
Drainage Mat Thickness (in)	1	2
Liner Parameters		
Material (sq. ft)	2,278	2,378

Installation Type: Choose the green roof installation type: modular or custom. A modular green roof system uses pre-constructed components to make green roof installation simpler. Modular installation types are only available for extensive roofs.

Building Height > 5 Stories: Select if the typical building height will exceed 5 stories. Taller buildings include additional costs for construction and maintenance of green roof systems.

Ponding Depth: Ponding depth sets the available storage depth above the surface of the technology. Ponding depth can range from 0-3 inches. Adjusting the ponding depth will affect the volume of water captured by a single technology.

Filter Media Depth: Filter media depth sets the thickness or depth of the filter media layer. Filter media depth can range from 2-6 inches for extensive roofs and 6-10 inches for intensive roofs. Adjusting the filter media depth will affect the volume of water captured by a single technology.

Drainage Layer Depth: Drainage layer depth sets the thickness or depth of drainage mat below the green roof. Drainage layer depth can range from 1-3 inches. Increasing the depth of the drainage layer will provide faster drainage for the green roof.

Vegetation Type: Choose from grass or diverse to define the vegetation which covers the technology area. If grass is selected, then vegetation installation type and mowing regime can be adjusted. If diverse is selected it is assumed that non-grass plants are installed. With diverse, a user can select the range of the number of species and percent flowering vegetation, which affect co-benefits.

Vegetation Installation Type: Vegetation installation type defines the method of installation used to install the grass vegetation that will cover the surface of the technology. Choose from three methods available for installation, seed, sod, and plug; with seed being the least expensive and plug being the most expensive.

# of Species: Define the number species planted in the technology. Increasing the number of species results in additional co-benefits.

% Flowering Vegetation: Define the percentage of vegetation that will occupy the surface of the technology that contains a flowering species. Higher percentage of flowering species increases the co-benefits provided by the technology.

Includes Irrigation System: Selecting this option means that the grass is in an area or is of a species that requires regular irrigation. Adding irrigation to a technology increases cost of the technology.

Irrigation Season: Define the number of months irrigation is required.

% Impervious Area Captured: The percent of impervious area for which runoff drains to the technology with the parameters selected above. The total % Impervious Area Captured for all technologies applied in a subunit cannot exceed 100%. For green roofs, the % Impervious Area captured should be equivalent to the amount of rooftop area will be replaced with green roof.

Technology Calculations

Green roofs are an area-based technology, therefore technology area is based solely on area and does not depend on captured volumes or technology volume capacity. The total impervious area required to be captured is found using Equation A.9. The area required to be captured is determined by the subunit area, percent imperviousness of the subunit, and percent impervious area captured. For green roofs it the percent impervious to captured was limited to be 50% of a sub-unit to avoid a user estimating more green roofs then would be possible to construct due to availability of rooftops. For green roofs, it is defaulted that **ALL** of the impervious area captured is replaced with green roofs with no surfaces running to them.

SWMM Parameters

Green roofs are modeled using the LID green roof module within SWMM. LID modules within SWMM use various layers with storage capacity combined with fluxes that represent different the stormwater practice. Within the green roof module there are three different layers, the ponding layer, filter media layer, and drainage layer. Figure A.10 (above) displays the various layers within the green roof as well as the different processes that are modeled for how water can enter and exit each layer. Table A.20 illustrates the parameters that were used for the green roof module in SWMM.

Table A.20: SWMM Technology parameters for green roof module

Ponding Layer	
Ponding Depth (inches)	User
Vegetation Volume Fraction	0.1

Surface Roughness (n)	0.1
Surface Slope (percent)	0
Filter Media Layer	
Filter Media Depth (inches)	User
Porosity	0.501
Field Capacity	0.284
Wilting Point	0.135
Conductivity (in/hr)	0.26
Conductivity Slope	60
Suction Head (in)	6.69
Drainage Layer	
Thickness (in)	1
Void ratio	0.5
Seepage Rate (in/hr)	0
Roughness (n)	0.25

APPENDIX B: CO-BENEFITS ESTIMATION APPROACH

ESTIMATION OF CO-BENEFITS SCORES IN CLASIC

An extensive review of co-benefits for stormwater control measures (CSMs) was conducted to determine appropriate indicators of co-benefits to include in CLASIC. CLASIC applies multi-criteria decision analysis (MCDA) using the weighted average method (Howard 1991; Janssen 2001; Zanakis et al 1998) to score performance of user developed scenarios in each economic, social, and environmental categories.

Based on the extensive literature review conducted, the CSU team has developed methodology for estimating performance scores for scenarios in co-benefit categories. Approaches were developed from the peer reviewed literature and other accepted co-benefit analysis tools (Table B.1). Estimation of scores for each indicator is based on CLASIC user selections for scenario and outputs as summarized in Table B.1. The approach for estimating each indicator is described briefly below:

Economic

Property Values: Property values increases have been found to be directly correlated to area of added green space (Ward et al., 2008; Lutzenhiser and Netusil, 2001; Shultz and Schmitz, 2008). CLASIC calculates a score for this indicator based on replacement of impervious area with stormwater technologies that include grass and/or diverse vegetation or wet ponds.

Costs from Illness: Pollutant removal (ozone, PM10, NO_2, SO_2, and CO) are estimated depending on area of herbaceous plants, number of trees, or area of green roof (Nowak et al., 2002; Jones et al., 2012) and the following equations, where pollutant removal factor (lb/ft^2-yr) is estimated from the literature (Nowak et al., 2002; Jones et al., 2012):

Based on area of herbaceous plants added:

Pollutant Removal (lb/yr) = (SCM are with diverse vegetation)*(Pollutant Removal Factor) (Eq. B1)

Based on number of trees added:

Pollutant Removal (lb/yr) = (number of trees)*(Pollutant Removal Factor) (Eq. B2)

Based on area of green roof added:

Pollutant Removal (lb/yr) = (area of green roof)*(Pollutant Removal Factor) (Eq. B3)

Costs related to health care illness were then estimated for each pollutant based on costs per ton of each pollutant removed (Nowak et al., 2014):

Cost Savings for Pollutant Removal ($/yr) = Polutant removal * cost per ton of removal (Eq. B4)

Avoided Costs from Combined Sewer Treatment: The user selects this indicator only if combined sewer overflow is an issue in their area. Cost savings from avoided combined sewer treatment are directly correlated to runoff volume reduction from stormwater technologies (Jones et al., 2012).

Potential Impacts from Nuisance Floods: The user selects this indicator only if nuisance flooding is an issue in their area. It is assumed that reductions in runoff volume result in reduced nuisance floods.

Building Energy Efficiency: Energy savings are estimated based on area of green roof (Doshi et al., 2005).

Table B.1. Summary of Approach to Estimate Co-Benefit Indicators

	Description of Approach	CLASIC parameters used for estimation
Economic:		
Property Values	Directly correlated to area of added green space[1]	SCM area (acre) only when vegetated is selected and technology is added to captured impervious
Costs from Illness	Ozone, PM10, nitrogen dioxide, sulfur dioxide, and carbon monoxide removal by each herbaceous plants and trees is estimated (lb/yr)[2]. Pollutant removal is used in conjunction with cost of illness treatment ($/yr)associated with each pollutant[3].	Diverse Vegetated SCM area (acre); Number of trees added; Area of Green Roof
Avoided Costs from Combined Sewer Treatment	Runoff volume[5]	Average annual precipitation that becomes runoff (in/yr)
Potential Impacts from to nuisance floods	Runoff volume	Average annual precipitation that becomes runoff (in/yr)
Building Energy Efficiency	Energy savings associated with green roof[4]	Green roof area (acre)

Avoided Water Treatment	Volume of stormwater harvested and used	Stormwater usage rate (gal/day)
Employment Opportunity	Annual maintenance per technology added	Annual maintenance per technology added (hrs/yr)
Social		
Health Impacts from Air Quality	Ozone, PM10, nitrogen dioxide, sulfur dioxide, and carbon monoxide removal by each herbaceous plants and trees is estimated (lb/yr)[2]. Reduction of these pollutants is related to decreased cases of illness[3].	Diverse Vegetated SCM area (acre); Number of trees added; Area of Green Roof
Mental Health	Directly correlated to area of added green space[5]	SCM area (acre) only when vegetated is selected and technology is added to captured impervious
Thermal Comfort	Percent reduction of urban heat island effect is estimated based on vegetation and soil[6].	SCM area (acre) only when vegetated is selected and technology is added to captured impervious
Indicator	**Description of Approach**	**CLASIC parameters used for estimation**
Increased Supply from Harvested Stormwater	Volume of stormwater harvested and used	Stormwater usage rate (gal/day)
Public Awareness of Stormwater and Water Systems	Density of SCMs added is correlated to public visibility and educational opportunities[5]	Number of SCMs / project area (acre)
Potential Avoided Social Strain Associated with Nuisance Flooding	Runoff volume	Average annual precipitation that becomes runoff (in/yr)
Environmental		

Ecosystem Services	Pollinator support score based on percentage flowering vegetation[5]	Vegetation selection - % of Flowering Vegetation (0 or >50%)
	Biodiversity score based on plant coverage and number of species planted[5]	Vegetation selection of Diverse and # of species (2, 3-9, >10)
	Green corridor support score based on presence of grass area[5]	Technology selection of large EDB gets credit, all others do not
Groundwater Flow	Infiltration volume	Average annual precipitation that infiltrates (in/yr)
Carbon Sequestration	Carbon sequestered (lb CO_2/yr) estimated based on addition of herbaceous plants, soil, and trees[7].	Diverse Vegetated SCM area (acre); Number of trees added; Area of Green Roof

1 - Ward et al. (2008); Lutzenhiser and Netusil (2001); Shultz and Schmitz (2008)
2 - Nowak et al. (2002); Jones et al. (2012)
3 - Nowak et al. (2014)
4 - Doshi et al.(2005)
5 - Jones et al. (2012)
6 - Li (2016); Oke (1987)
7 - Getter et al. (2009); Jo and McPherson (1995)

Avoided Water Treatment: Costs avoided for water treatment is estimated based on volume of harvested stormwater.

Employment Opportunity: Employment opportunity is assumed to be directly correlated to annual maintenance required for the technologies added, calculated as part of the technology cost.

Social

Health Impacts from Air Quality: Reductions in illness have been directly related to removal of ozone, PM10, NO_2, SO_2, and CO (Nowak et al., 2014). Removal of these air pollutants is estimated based on Eq. A1 – A3.

Mental Health: Improvements in mental health have been directly associated to area of added green space (Jones et al., 2012). CLASIC calculates a score for this indicator based on replacement of impervious area with stormwater technologies that include grass and/or diverse vegetation or wet ponds.

Thermal Comfort: When technologies that include are placed in impervious area, thermal comfort is estimated based on area of vegetated area, bare soil, or permeable pavement. This area is multiplied by a factor of 0.25 for grass and diverse vegetation, 0.11 for bare soil, and 0.05 for permeable pavement (Li, 2016; Oke, 1987).

Increased Supply from Harvested Stormwater: The social benefit of increased and diverse water supply is estimated by volume of harvested stormwater.

Public Awareness of Stormwater and Water Systems: The density of visible stormwater technologies is directly related to awareness and educational opportunities (Jones et al., 2012). Two equally weighted sub-indicators were used to estimate performance for this indicator including the number of technologies per total area and area of added technologies per total area.

Potential Avoided Social Strain Associated with Nuisance Flooding: The user selects this indicator only if nuisance flooding is an issue in their area. It is assumed that reductions in runoff volume result in reduced nuisance floods.

Environmental

Ecosystem Services: There are four equally weighted sub-indicators that are used to estimate ecosystem services (Jones et al., 2012)

Pollinator Score:

- When the technology does not include vegetation, score = 0
- When the technology includes vegetation and % flowering vegetation is set to 0%, score = 1
- When the technology includes vegetation and % flowering vegetation is set to >50%, score = 2

Biodiversity Score:

- When the technology does not include vegetation, score = 0
- When the technology includes vegetation and plant species = 1-2, score = 1
- When the technology includes vegetation and plant species = 3-9, score = 2
- When the technology includes vegetation and plant species = 10+, score = 3

Green Corridor Score: Only addition of a large detention basin gets a score of 1 for this indicator. All other technologies score 0.

Groundwater Flow: Increase in groundwater flow is directly related to volume infiltrated.

Carbon Sequestration: Mass of carbon sequestered per year is estimated based on CO_2 sequested by trees added and area of vegetation added (Getter et al., 2009); Jo and McPherson, 1995)

APPENDIX C: LIFE CYCLE COST ESTIMATION APPROACH

The Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC) tool enables the comparative cost, performance, and co-benefits of stormwater technology scenarios.

Several alternative economic evaluation techniques exist to compare cost scenarios, e.g., benefit-cost, saving-to-investment ratios, internal rate of return (IRR), net benefits, net savings, and payback methods (NIST, 1996). These analyses typically include a defined time of cost and benefit accrual and assess single or multiple projects. However, these techniques necessitate revenue or borrowing data, may not include a categorization of costs, focus on one aspect of a project (benefit or savings), and have analyses such as IRR or payback. These analyses help with some aspects of cost planning however the feasibility level analysis that is most applicable to multiple municipal entities is the life cycle cost overtime. CLASIC outputs provide cost over time for capital maintenance and rehabilitation which informs stormwater implementation costs and feasibility level budget planning.

Other economic analyses fall under the umbrella term "Life Cycle techniques" and include all relevant costs over time. Including all applicable costs provides greater accuracy in assessing economic performance (Ruegg et al., 1980). Some analyses typically termed lifecycle analysis (LCA), also include monetization of benefits external to the construction and maintenance of the project (e.g. positive health outcomes, greenhouse gas reduction, or impact of reduced air pollution). Other forms include only costs relative to the life of an asset, typically termed lifecycle cost analysis (LCC) (Norris, 2001). The CLASIC tool connects the user with the costs most closely tied to implementing, managing, and budgeting for stormwater assets. The LCC technique was selected over the LCA technique to focus on the costs to the municipality which directly impact municipal budgeting, utility fee setting and management, and capital expenditure planning. An excellent summary comparison from Norris (2001) of the two techniques is below in Table 1.

Table 1 How LCA and LCC differ in purpose and approach (Norris, 2001)

Tool/Method	LCA	LCC
Purpose	Compare relative environmental performance of alternative product systems for meeting the same end-use function, from a broad, societal perspective	Determine cost-effectiveness of alternative investments and business decisions, from the perspective of an economic decision maker such as a manufacturing firm or a consumer
Activities which are considered part of the 'Life Cycle'	All processes causally connected to the physical life cycle of the product; including the entire pre-usage supply chain; use and the processes supplying use; end-of-life and the processes supplying end-of-life steps	Activities causing direct costs or benefits to the decision maker during the economic life of the investment, as a result of the investment
Flows considered	Pollutants, resources, and inter-process flows of materials and energy	Cost and benefit monetary flows directly impacting decision maker
Units for tracking flows	Primarily mass and energy; occasionally volume, other physical units	Monetary units (e.g., dollars, euro, etc.)
Time treatment and scope	The timing of processes and their release or consumption flows is traditionally ignored; impact assessment may address a fixed time window of impacts (e.g., 100-year time horizon for assessing global warming potentials) but future impacts are generally not discounted	Timing is critical. Present valuing (discounting) of costs and benefits. Specific time horizon scope is adopted, and any costs or benefits occurring outside that scope are ignored

Project Area and Simultaneous Scenario Analysis

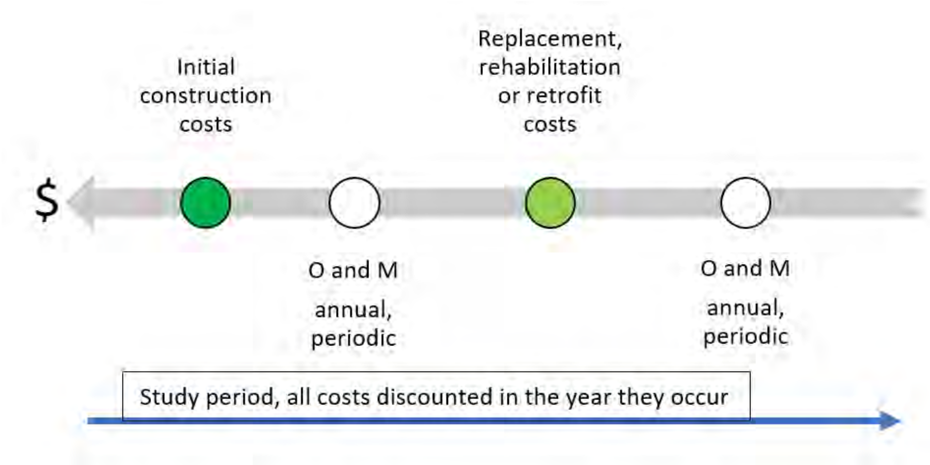
When using CLASIC, users define a geographic area of interest ("project area") in a GIS interface as small as a census block to as large as a HUC 10 watershed. The user can input multiple scenarios to explore scenario performance differences, such as a change in water quantity managed and the amount of pollutants (sediment, nitrogen, and phosphorus) removed. For each comparison, the project area should not change as the comparison should have the same baseline condition and geographic and data input from the national databases the tool pulls from for soils (SSURGO/STATSGO), slope (DEM), landuse (NLCD), and climate (EPA Basins Model).

Once the project area is selected, the user runs a baseline scenario and then inputs various sizes, characteristics and combinations of stormwater technologies for other scenarios. The computation of the LCC associated with each scenario enables the user to compare which scenario offers the lowest LCC and the most cost-effective solution in dollars per quantity, the area treated or pounds of pollution reduced. Multiple cost comparisons allow the user to select the outputs most informative to their specific stormwater program, assess returns to scale, and economies of scale through various BMP choices and quantities. The "lowest LCC" is not necessarily the singular comparison to use in decision making, and CLASIC provides multiple comparisons in performance and cost-effectiveness (Ruegg and Marshall, 1990). The innovation that CLASIC offers the user from existing stormwater cost tools is that the user is able to obtain output for simultaneous, multi-BMP performance and cost for the project area.

Life Cycle Cost Method in CLASIC

The purpose of using the LCC method is to explicitly define investment decisions that impact the total lifetime costs across alternatives. It is a method for assessing the total cost of asset ownership, which allows the user to compare various decisions where costs occur over time. The general LCC method includes a study period; initial and periodic capital, operation, and maintenance costs; an applicable discount rate; and price inflation factors to calculate the net present value (NPV) of an investment (Figure 1).

The LCC method in CLASIC does not include benefit values (monetary) or revenue flow, As such, the present value (PV) is computed rather than an NPV. The CLASIC LCC calculates costs of technology construction, associated maintenance, and rehabilitation costs overtime. The purpose of the cost analysis in the tool is to assist municipal decision-makers in planning and budgeting for stormwater practices.



This tool helps determine how to achieve performance goals and take those practices into account simultaneously. Accounting for total life costs enables the municipality to create budgets that represent the potential municipal expenditures overtime. Taking the life cost of stormwater technology into account helps avoid underestimating costs. Failing to estimate and plan for stormwater expenses can result in overspending, underspending, or negative cash flow.

The innovation that CLASIC LCC provides to its municipal stormwater audience is the coupling of cost and performance of stormwater BMP scenarios and making explicit the importance of maintenance and rehabilitation on total lifetime costs. CLASIC users choose between many best management practice characteristics that vary in size and cost. The costs for each of these selections (construction and maintenance) were developed through a "cost buildup" approach by the University of Utah (UU).

General Description of Costs Included in LCC

Much work has been done to evaluate and collect data on capital costs (construction) of green infrastructure. However, less data exists in a commensurate or reportable fashion for operations and maintenance costs (see Clary and Piza eds, 2017). Each technology in the CLASIC tool has associated capital,[1] maintenance frequency and effort, as well as replacement/rehabilitation costs associated with those maintenance frequencies. CLASIC follows NIST guidance (1996) and treats professional and land purchase costs occurring outside of construction as "sunk costs" and does not include these. However, CLASIC construction costs do include a percent of total cost allocated toward engineering and contingency (20% total). All costs are regionalized based on a study prepared specifically for CLASIC by the University of Utah, Geosyntec Consultants, and Wright Water Engineers titled "Standardization of Unit Costs and Regional Adjustment Factors." Multiple existing cost tools were consulted (e.g WERF SELECT tool, NCHRP REPORT 792, 2014, and National Stormwater Calculator) in the development of construction and maintenance costs for CLASIC. The full literature consulted for costs was prepared by the University of Utah.

Construction Cost Categories in CLASIC

Each technology has a variety of sizes and options to select that are tied to the costs. The following is an example of construction cost categories are included in CLASIC:

Table 2: Construction Cost Categories

Mobilization	Vegetation - Typical
Clearing & Grubbing	Slotted PVC Underdrain Pipe1
Dewatering	PVC Liner2
Excavation (0 - 1000)	Hydroseed
Excavation (1000 - 10,000)	Inflow Structure(s)
Excavation (10,000+)	Outflow Structure(s)
Haul/Dispose of Ex Material	Overflow Structures(s)
Soil Media / Planting Media	Demolition
Filter Media (Gravel fill 3/4")	

[1] "Capital" expense typically refers to the method in which funds are secured and spent by a municipality. CLASIC will not differentiate between the ways in which funds are secured (e.g. referendum, utility, or general fund) or restrictions on expenditure – therefore general labels of construction and maintenance cost do not reflect an assumption of how the funds are generated.

The cost buildup is complex and accounts for not only sizes but options for landscaping (grass or more expensive plant material) and other materials such as soil and mulch that vary. For example, the bioswale practice has 12 options that allow for the selection of whether to include landscaping, underdrains, or liners.

Maintenance Cost Categories for CLASIC BMPs

Green infrastructure maintenance cost tracking and reporting has been limited. There are several reasons outlined in "Cost of Maintaining Green Infrastructure;" namely, that stormwater programs are newer than other infrastructure sectors, the lack of consistent and standardized reporting, the range of factors that impact maintenance costs, and the underutilization of existing asset management tools to track and report costs (Clary and Piza eds, 2017). As a follow-up publication, WRF released "Recommended Operation and Maintenance Activity and Cost Reporting Parameters for Stormwater Best Management Practices Database" in 2018 to address the standardization of reporting (WRF, 2018).

To build on existing information and offer a solid step in stormwater planning, the CLASIC tool incorporates recognized maintenance cost categories (see for example U.S. EPA National Stormwater Calculator, 2014 and National Academies of Sciences, Engineering, and Medicine, 2014). These costs occur post-construction and are necessary to ensure or verify the continued effectiveness of the technology. The bulk of the green infrastructure maintenance costs accrue on an annual basis and may include only labor and equipment, or additional periodic and material costs, including contractor markups such as overhead and profit, associated with activities such as monitoring, operating and maintaining.

The CLASIC LCC maintenance inputs include frequencies and effort of maintenance from a review of guidance manuals from across the nation (collected by University of Utah). Maintenance requirements are summarized, categorized and associated with labor, materials, and equipment costs for an estimate of annual and periodic costs. These costs are averaged and used as annual costs of maintenance. The recommended maintenance frequency is based on this review of guidance manuals. These guidance manuals also indicated specific regional maintenance considerations that are within the maintenance effort costs in CLASIC LCC.

The timing of major replacement (or rehabilitation) costs are based on the estimated "years to rehabilitation" from reviewed literature. Rehabilitation cost build-up is based on summing lines within the initial capital (construction) costs applicable to a more major effort to replace and reestablish the function of the technology. For example rehabilitation costs include costs such as Mobilization, Clearing & Grubbing, Dewatering, Excavation, Haul/Dispose of Ex Material, Filter Media, Mulch, Vegetation, Hydroseed, Engineering (10%), and Contingency (10%) that are technology size dependent.

Study Period

The user selects the study period in CLASIC for the span of 10, 20, 30 or 50 years. The study period should be the same for all scenarios considered, therefore the maintenance cost frequency will be automatically adjusted to the study period. For example, if the "years to rehabilitation" indicates it will be 10 years before significant rehabilitation cost occurs, and the study period selected is 20 years, the LCC will input two rehabilitation cost occurrences.

Present Value Formulas (NIST, 1996)

The purpose of using a PV formula is to account for the "time value of money" over the life of the scenario. That is, a dollar today is worth less over time due to inflation and other factors which account for the value of other opportunities the user may have for the funds being used (explained further in the discounting section). A typical LCC takes initial investments and future costs, applies a discount value (or factor), and sums all costs over time to provide a monetary comparison between scenarios. The calculation of PV "corrects" all future costs which allows the costs to be summed together and compared as a present dollar value.[2]

The LCC formula for PV used in the CLASIC tool is a standard formula used in infrastructure and feasibility level planning (see NIST, 1996; USACE/EPA, 2000; USEPA, 2008). The different costs municipalities incur include construction, operations/maintenance, and retrofit or repair.

$$LCC = C_0 + \left[\sum_{t=1}^{T} \frac{MC_t}{(1+i)^t} + \sum_{t=1}^{T} \frac{RC_t}{(1+i)^t}\right]$$

Construction costs (C_0) are upfront (treated as occurring at year 0). The maintenance costs (MC_t) occur annually though the study period. Rehabilitation costs (RC_t) occur with frequency specified as "years to rehabilitation." No explicit cost for operations (administrative or indirect costs) are included as a separate cost build up. However, the maintenance cost buildup includes line items for compliance inspection and overhead (see UU cost build up).

Discount Rate and CLASIC tool functionality

The discount rate in PV calculations transforms expenditures that occur at different times throughout the study period to current values. Economic theory suggests selecting a discount rate to reflect the "opportunity cost" of the project relative to other investments (i.e. the rate in other investment opportunities or to account for the "cost of capital"). The selected discount rate accounts for future uncertainties and adjusts the cash flows to values that can be added

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[2] In addition, options between green and gray infrastructure may create greater or lesser benefits (such as green space, native habitat, thermal effects) and those benefits would be incorporated into a life cycle assessments (LCA) where all environmental flows are quantified and summed to a NPV. The benefit (co-benefit) analysis within CLASIC is relative scoring and not monetary value but provides a benefit measure in graphical form.

and compared as present values. Different discount rates are used depending upon uncertainty of different investments such as federal water and energy projects, cost-effectiveness analysis, lease/purchase, internal government investment, and asset sales (see NIST, 1996; FEMP, 2018; OMB, 2018).

The selection of a discount rate is a complex and important decision. If a high discount rate is used the output will display low PV which could suggest to the user a lower budgetary allocation is required to implement and maintain the stormwater BMPs than what is actually needed. In order to present the user with costs that are reasonable and eliminate confusion and potential for excessively high or erroneous discount rate selection, the default for the CLASIC tool will use undiscounted current dollar value (unadjusted for inflation) for each time step involved in the calculation. Summing current dollar values throughout the study period assumes that the discount rate is the same as the rate of increase in other construction and maintenance costs. This is a valid simplification for the user while also accounting for a potential, but not user explicit, escalation of labor and materials. The intent for this tool is to provide the user with feasibility level costs, not final construction costs.

In the event the user would like to conduct a sensitivity analysis and incorporate a discount value, the tool allows for a selection of between 1 - 5%. Current rates for federal projects are below 5% (U.S. Office of Management and Budget, 2019). Cost effectiveness analysis typically uses the "real" discount rate which is adjusted for inflation, not the nominal rate. Evaluating a range of discount rates helps reflect what is called "the social rate of time preference…The social rate of time preference reflects the fact that most projects conducted for the public good should provide benefits for future generations. In these cases, the time value of money (and the discount rate) is lower because there is a preference to more equally allocate benefits and costs across time" (pg. 21, Clements and Henderson, 2015). A sensitivity analysis has a lower and upper discount range reported for the LCC.

Equivalent Annualized Costs

Another way the costs are displayed to inform the user of costs over time is the annualized cost. This displays the costs that breaks the PV into equal amounts every year which helps understand the cash flow in any year. This comparison helps the user see annual potential cost differences in budgeting where scenarios may have very different capital or maintenance costs. It can also be used if the scenarios have different study periods. Annualized costs take discounting into the calculation - therefore if the default (zero) is used, annualized costs are the PV divided by the study period. The formula for calculating annualized costs is:

$$\mathrm{EAC} = \frac{NPV}{A_{t,r}}$$

Where:

$$A_{t,r} = \frac{1 - \frac{1}{(1+r)^t}}{r}$$

NPV is net present value (or PV in the case for CLASIC)

r is the annual real discount rate and

t is the number of years

Annual Cost of Nutrient Load Reduction

As part of the cost comparison between scenarios - CLASIC displays the dollars per pound removed for pollutants: total suspended solid, total nitrogen, total phosphorus, or fecal indicator bacteria. The performance in pounds of pollutant reduced is compared to the total PV cost and displayed as "average annual $/lb removed." This may be of interest if a particular pollutant is the main target to reduce, such as phosphorus in freshwater or nitrogen in more saline waters.

APPENDIX D: SUMMARY OF GRAPHICAL OUTPUTS

SUMMARY PAGE

Note that summaries of graphical outputs are also included in the question mark help button next to each set of graphical outputs.

Hydrologic Data: Average annual runoff, infiltration, and evaporation are estimated based on the climate data selected by the user. If a time period of less than 5 years was selected for climate data, graphics show results for each year. If a time period of more than 5 years was selected for climate data, box plots are shown where boxes represent the 25th percentile confidence interval.

Lifecycle Cost Analysis: This graphic estimates present value cost over the user specified study period. Construction, maintenace, and rehabilitation costs are reported separately.

Co-Benefit Analsysis: A score is estimated based on indicators for each social, economic, and environmental categories based on multi-criteria decision analysis. Scores can range from 0 – 5, where 5 is the highets possible score. Note that scenarios are compared to each other and all scenarios included in your analysis are compared against each other (not only the three shown on this page).

Hydrologic Performance: The average percentage change in runoff volume from the baseline is estimated based on the climate data selected.

COST PAGE

Hydrologic Data: Average annual runoff, infiltration, and evaporation are estimated based on the climate data selected by the user. If a time period of less than 5 years was selected for climate data, graphics show results for each year. If a time period of more than 5 years was selected for climate data, box plots are shown where boxes represent the 25th percentile confidence interval.

Lifecycle Cost Analysis: This graphic estimates present value cost over the user specified study period. Construction, maintenace, and rehabilitation costs are reported separately.

Average Annual Cost Over Design Life: Present value cost is averaged annually over user specified study period.

Time Series of Costs: Annual costs are estimated over the user specified study period.

Co-Benefits Page

Hydrologic Data: Average annual runoff, infiltration, and evaporation are estimated based on the climate data selected by the user. If a time period of less than 5 years was selected for climate data, graphics show results for each year. If a time period of more than 5 years was selected for climate data, box plots are shown where boxes represent the 25th percentile confidence interval.

Score for individual indicators in Social, Environmental, and Economic Categories (5 is best*): A score is estimated based on indicators for each social, economic, and environmental categories based on multi-criteria decision analysis. Scores can range from 0 – 5, where 5 is the highets possible score. Note that scenarios are compared to each other and all scenarios included in your analysis are compared against each other (not only the three shown on this page).

Total Co-Benefits Score (maximum is 15): The score of each social, economic, and environmental categories are displayed stacked to demonstrate overall score for co-benefits. Note that scenarios are compared to each other and all scenarios included in your analysis are compared against each other (not only the three shown on this page).

Score for individual indicators in Social, Environmental, and Economic Categories (5 is best*): The score for each indicator that contributies to social, economic, and environmental category permormance is reported. Select which category you would like to view (social, economic, or environmental). A score of 5 does not indicate that the scenario performs at the maximum potential for an indicator, but rather that it performs best compared to other scenarios.

Hyd. & W.Q Page

Hydrologic Data: Average annual runoff, infiltration, and evaporation are estimated based on the climate data selected by the user. If a time period of less than 5 years was selected for climate data, graphics show results for each year. If a time period of more than 5 years was selected for climate data, box plots are shown where boxes represent the 25th percentile confidence interval.

Percentage Change in Volumes from Baseline Scenario (+ indicates increase from baseline, - indicates decrease from baseline): Select runoff, infiltration, or evaporation to view the average percentage change in volume from the baseline, estimated based on the climate data selected.

Percentage Change in Contaminant Load from Baseline Scenario (+ indicates increase from baseline, - indicates decrease from baseline): The average percentage change in load from baseline of each total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP), and fecal indicator bacteria (FIB) is estimated.

Annual Cost of Nutrient Load Reduction: Average annual cost per lb of nitorgen and phosphorus reduced by the scenario is estimated.

Allocation Between Runoff, Infiltrated, Evapotranspired, and Harvested Volume: The percentage of precipitation that ends up as runoff, infiltrated, evapostranspired, or harvested is estimated.