SUPPLEMENTARY MATERIAL

DEVELOPMENT AND APPLICATION OF THE COMMUNITY-ENABLED LIFECYCLE ANALYSIS OF STORMWATER INFRASTRUCTURE COSTS (CLASIC) TOOL

Submitted by

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SUPPORTING MATERIAL FOR CHAPTER 3: SPECIFICATIONS FOR TECHNOLOGY PARAMETERS FOR CLASIC

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. 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 (USEPA, 2026).

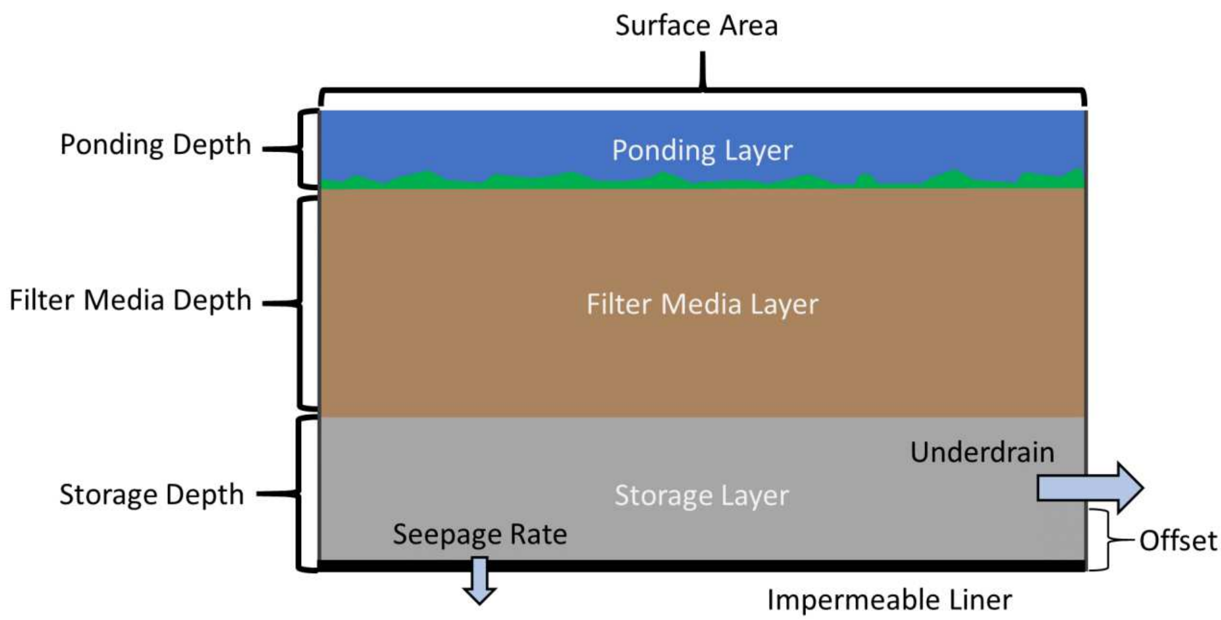

Figure 1: Diagram of a rain garden as it is represented in SWMM module of CLASIC.

Figure 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 technology changes the surface area as well as defaults for the parameters below including ponding depth, filter media depth, and number of trees. Table 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 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 1.

Equation 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 2. 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 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 3.

Equation 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 4. 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 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 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 2 displays the parameters used for the bioretention unit to model rain gardens in SWMM.

Table 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 (USEPA, 2026).

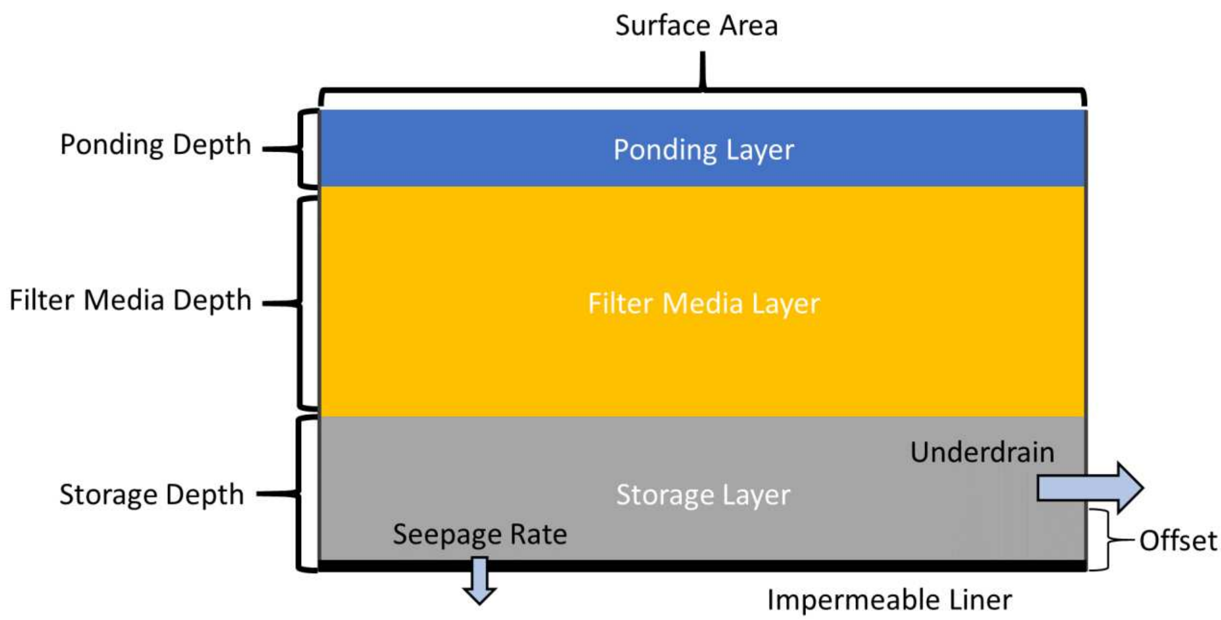

Figure 2: Diagram of a sand filter as it is represented in SWMM module of CLASIC.

Figure 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 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 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 1. Based on the user selections for the sand filter, a unit capacity can be calculated using **Error! Reference source not found.**. For sand filters, like rain gardens, the unit capacity w as 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 3. After the number of technologies is determined, the total area required to provide the necessary captured volume is determined using Equation 4. 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 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 4 illustrates the parameters that were used for the bioretention unit to model sand filters in SWMM.

Table 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 (UEPA, 2026).

Figure 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.

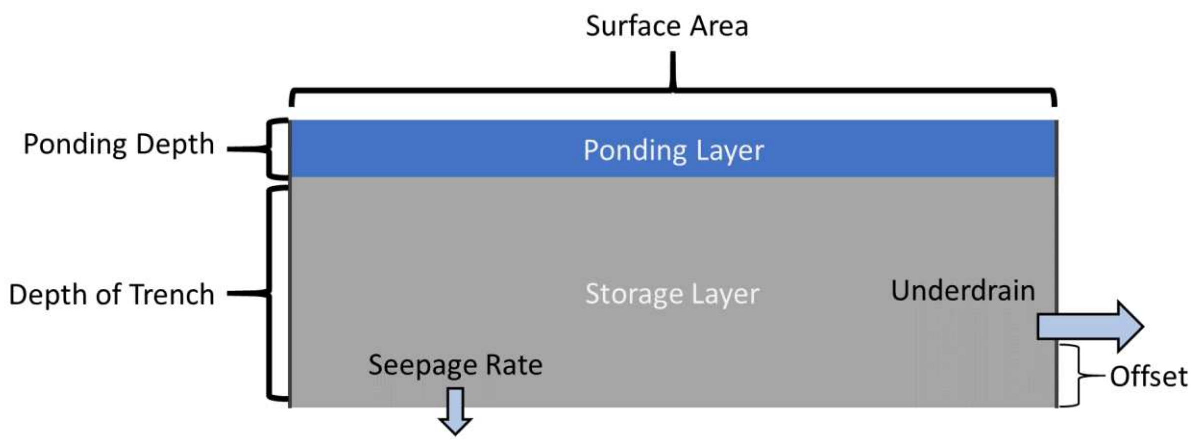

Figure 3: Diagram of an infiltration trench as it is represented in SWMM module of CLASIC.

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 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 5: Infiltration trench parameters 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 1. Based on the user selections for the infiltration trench, a unit capacity can be calculated using Equation 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 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 3. After the number of technologies is determined, the total area required to provide the necessary captured volume is determined using **Error! Reference source not found.** The technology area represents the pervious area that a ccepts 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 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 6 illustrates the parameters that were used for the infiltration trench unit to model infiltration trenches in SWMM.

Table 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 (USEPA, 2026).

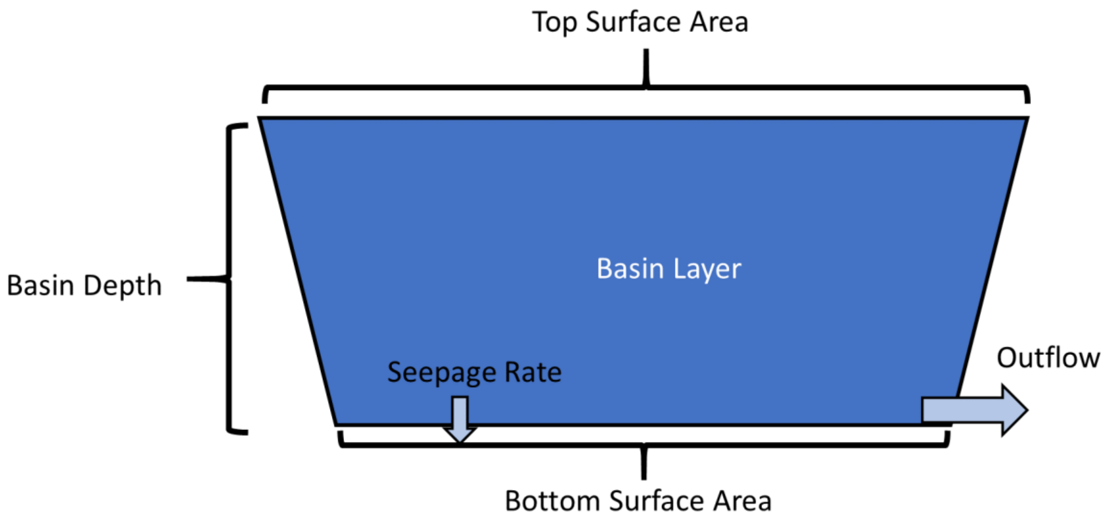

Figure 4: Diagram of a detention basin as it is represented in SWMM.

Figure 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 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.

Table 7: Detention basin parameters 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’

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.

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 1. 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 3. After the number of technologies is determined, the total area required to provide the necessary captured volume is determined using Equation 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 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 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 8 displays the parameters that were used for the infiltration trench unit to model detention basins in SWMM.

Table 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	$\dfrac{\text{Basin Depth x } 12\ (\frac{\text{in}}{\text{ft}})}{Drain\ Time}$
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 in order 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 (USEPA, 2026).

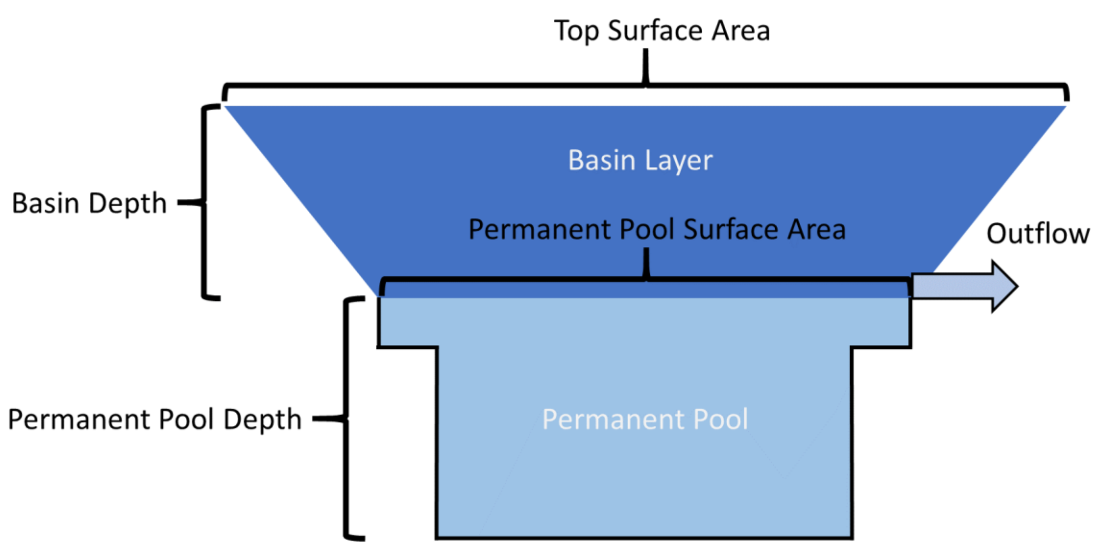

Figure 5: Diagram of a wet pond as it is represented in SWMM module of CLASIC.

Figure 5displays 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 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 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 1. 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 3.

After the number of technologies is determined, the total area required to provide the necessary captured volume is determined using Equation 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 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. Figure 5 displays the parameters that were used for the infiltration trench unit to model wet ponds in SWMM.

Table 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

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. (USEPA, 2026).

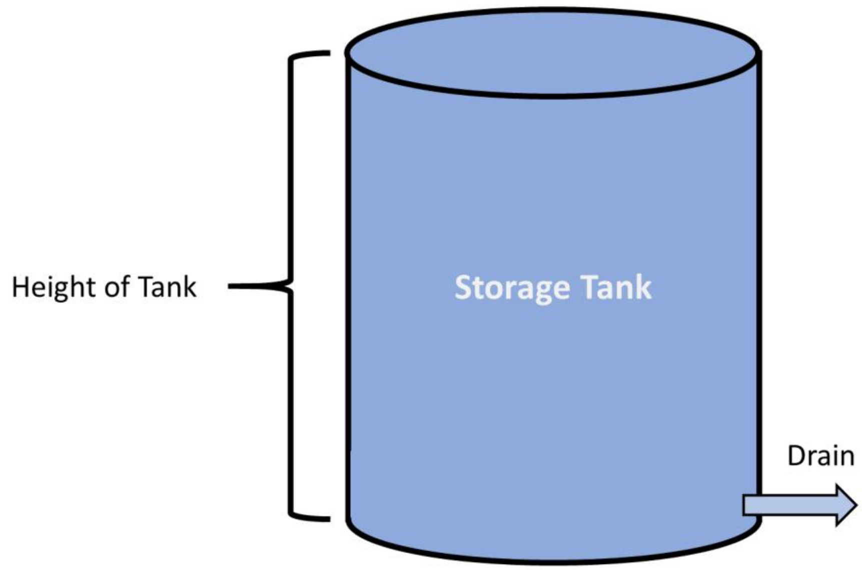

Figure 6: Diagram of stormwater harvesting as it is represented in SWMM module of CLASIC.

Figure 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 11shows 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 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 1. Based on the user selections for the stormwater harvesting, a unit capacity can be determined. 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 7 simply converts the cistern capacity to cubic feet instead of gallons.

Equation 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 3. After the number of technologies is determined, the total technology area required to provide the necessary captured volume is determined using Equation 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 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 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 12 illustrates the parameters that were used for the rain barrel unit to model stormwater harvesting in SWMM.

Table 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	$\dfrac{\left(\text{Height of Tank} * 12\left(\frac{\text{in}}{\text{hr}}\right)\right)}{\frac{Capacity}{Usage\ Rate} * 24\left(\frac{hr}{day}\right)}$
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 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 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.

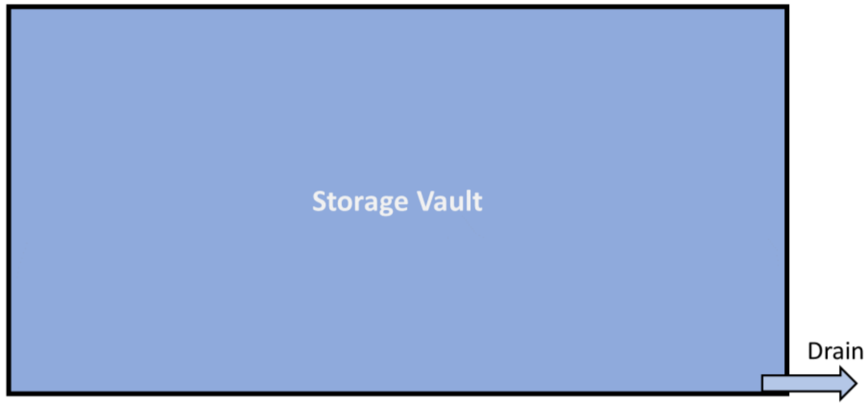

Figure 7: Diagram of a storage vault/tank as it is represented in SWMM module of CLASIC.

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 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 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 1. Based on the user selections for the storage vaults, a unit capacity can be determined. 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 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 3. After the number of technologies is determined, the total technology area required to provide the necessary captured volume is determined using Equation 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 stormwater practices. Within the rain barrel module there is a single layer, the storage layer. Figure 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 14 illustrates the parameters that were used for the rain barrel unit to model storage vaults in SWMM.

Table 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).

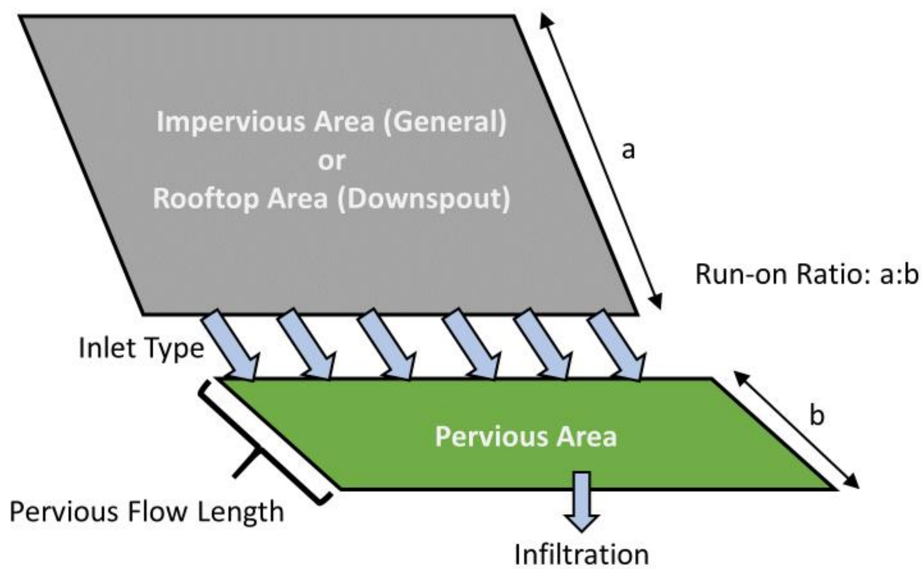

Figure 8: Diagram of disconnection as it is represented in SWMM module in CLASIC.

Figure 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 9. The area required to be captured is determined by the subunit area, percent imperviousness of the subunit, and percent impervious area captured.

Equation 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 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 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 11 is used to determine the technology area.

Equation 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 8 (above) displays how disconnection is modeled within SWMM. Table 15 illustrates the parameters that were used for modeling disconnection in SWMM. Because only subcatchments were used for modeling disconnection, Table 15 displays how the subcatchment parameters were determined for the pervious area in CLASIC.

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

Subcatchment Parameters	
Area (acres)	Equation 10 & Equation 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 (USEPA, 2026).

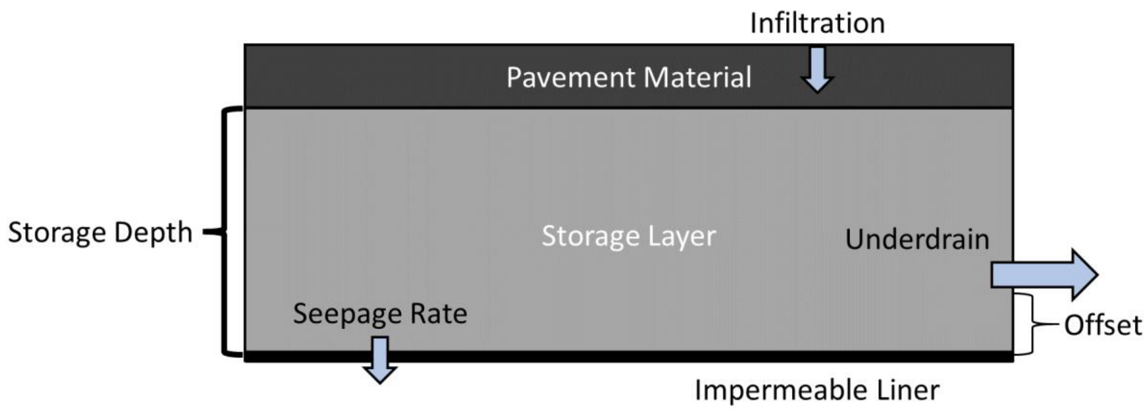

Figure 9: Diagram of permeable pavement as it is represented in SWMM module of CLASIC.

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.

Options for Modifying Design Parameter Defaults

Table 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 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 17 shows the maximum depths of precipitation to capture for the various storage depths at different run-on ratios.

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

Storage Depth	Maximum Capture Depths per Run-On Ratios		
(inches)	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 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 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 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 18 illustrates the parameters that were used for the permeable pavement unit in SWMM.

Table 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 (USEPA, 2026). Figure 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.

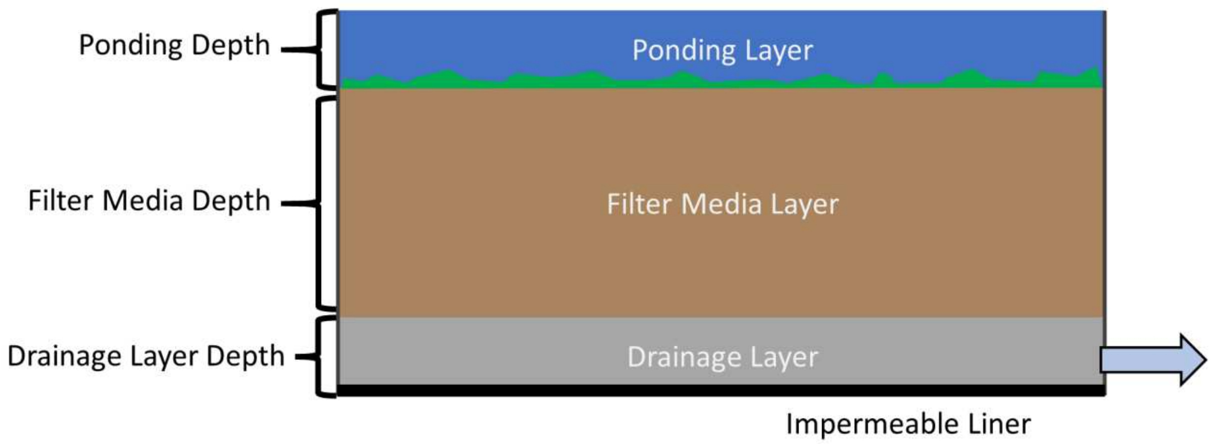

Figure 10: Diagram of a green roof as it is represented in SWMM module of CLASIC.

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 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 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 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 than 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 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 20 illustrates the parameters that were used for the green roof module in SWMM.

Table 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

Co-Benefits Indicators

The following shows each indicator is determined and summarizes how various technology unit parameters as well as outputs are used for the calculations of indicators.

Environmental			
Indicator	**Unit**	**Description of approach**	**Additional information**
Ecosystem Services	-	Includes 3 sub-criteria[1] with equal weights: Pollinator support score based on percentage flowering vegetation. Biodiversity score based on plant coverage and the number of species planted. Green corridor support score based on the presence of grass area.	**1. Pollinator support score:** • If there is no vegetation, then score = 0 • If there is vegetation and % Flowering Veg. = 0-50%, then score = 1 • If there is vegetation and % Flowering Veg. >50%, score = 2 **2. Biodiversity:** • If there is no vegetation, then score = 0 • If there is vegetation and plant species = 1-2, then score = 1 (Grass is considered as 1 specie) • If there is vegetation, and plant species = 3-9, then score =2 • If there is vegetation, and plant species = 10+, score =3 **3. Green Corridor:** • If technology = Extended Detention Basin and Class = Large, then score = 1, otherwise the score is 0.
Groundwater Flow	in/yr	Increase in groundwater flow is directly related to the volume infiltrated.	The scenario with the most volume of infiltrated water gets a score = 5, and the one with the least amount of infiltrated water gets score =0. The other scenarios get their scores by interpolation between 0 to 5.

Carbon Sequestration	lb CO_2 sequestrated/yr	Carbon sequestrated (lb CO_2/yr) is estimated based on the addition of herbaceous plants, soil, and trees.[2]	• **For Raingarden, If "vegetation"** = diverse and "technology Placement" = Captured Impervious: *Lb CO_2 sequestered/yr* ={ [(0.0181)*(SCM area (acres) * 43560 ft^2/acre]+[(0.14)*(SCM area (acres)*43560 ft^2/acre)]+ [(Number of Trees)*8]}*3.67CO_2/C • **For Raingarden, If "vegetation"** = diverse and "technology Placement" = Surrounding pervious: *Lb CO_2 sequestered/yr* ={ [(0.0181)*(SCM area (acres) * 43560 ft^2/acre]+ [(Number of Trees)*8]}*3.67CO_2/C • **For Extended Detention Basin or Grass Swale**, if "technology Placement" = Captured Impervious: *Lb CO_2 sequestered/yr* = [(0.14)*(SCM area (acres)*43560ft^2/acre)+ Number of trees*8] *3.67CO_2/C • **For Extended Detention Basin or grass swale**, if "technology Placement" = Surrounding Pervious: *Lb CO_2 sequestered/yr* = [(Number of Trees)*8]*3.67CO_2/C • **For Green Roof:** *Lb CO_2 sequestered/yr* = 0.07*SCM area(acre)*4360ft^2/acre*3.67CO_2/C • **All others,** score = 0
Social			
Health Impacts from Air Quality	lb/yr	Reductions in illness have been directly related to removing Ozone, PM10, NO2, SO2, and CO.[3]	The equations and factors used are listed in the supplementary material.
Mental Health	-	Improvements in mental health have been directly associated with the area of added green space.[1] CLASIC calculates a score for this indicator based on the replacement of impervious areas with stormwater technologies that include grass	• If there is no vegetation, then score = 0 (except for wet pond) • If there is vegetation or if technology = wet pond, and "technology Placement" = Captured Impervious, then score = SCM area (acre) • If "technology Placement" = Surrounding Pervious, then score = 0.

		and/or diverse vegetation or wet ponds.	
Thermal Comfort	acre	The percent change in the urban heat island effect is estimated based on vegetation and soil.[4]	When technologies are placed in impervious areas, thermal comfort is estimated based on the vegetated area, bare soil, or permeable pavement. This SCM area (acre) is multiplied by a factor of 0.25 for grass and diverse vegetation and for wet ponds, 0.11 for bare soil (when the sand filter or infiltration trench is used), and 0.05 for permeable pavement (Li, 2016; Oke, 1987).
Increased Supply from Harvested Stormwater	gallons/day	This indicator is correlated with the volume of stormwater harvested and used	The scenario with the biggest harvested volume gets a score = 5, and the one with the lowest harvested volume gets a score = 0. The other scenarios get their scores by interpolation between 0 to 5.
Public Awareness of Stormwater and Water Systems	-	Density of SCMs added is correlated to public visibility and educational opportunities.[1]	There are two equally weighted sub-criteria with scores between 0 to 5 for the technologies other than vault: • Sub-criterion 1 =Number of technologies/total study area • Sub-criterion 2 = Area of added technologies/ total study area The scenario with the biggest value gets a score = 5, and the one with the least value gets a score = 0. The other scenarios get their scores by interpolation between 0 to 5.
Potential Avoided Social Strain Associated with Nuisance Flooding	in/yr	This indicator is correlated with the runoff volume.	The scenario with the lowest runoff volume (in/yr) gets a score = 5, and the one with the biggest runoff volume gets a score = 0. The other scenarios get their scores by interpolation between 0 to 5.
Economic			
Property Values	acre	This indicator is directly correlated to the area of added	The scenario with the highest green area or wet pond gets a score= 5, and the scenario with the minimum green area or

		green space or wet pond[5] when "Technology Placement" = "Captured Impervious"	wet pond gets a score=0. The other scenarios get their scores by interpolation between 0 to 5.
Costs from illness	\$/yr	Cost saving from pollutant removal (\$/yr) = Pollutant removal(lb/year)*0.0005 (ton/lb) * cost per ton of removal(\$/ton)	The costs are calculated only for Ozone, NO_2, and SO_2, based on (Nowak, 2014). The equations and factors used are listed in the supplementary material.
Avoided Costs from Combined Sewer Treatment	in/yr	This indicator is correlated with the runoff volume.[1]	The scenario with the lowest runoff volume (in/yr) gets a score = 5, and the one with the biggest runoff volume gets a score = 0. The other scenarios get their scores by interpolation between 0 to 5.
Potential Impacts from nuisance floods	in/yr	This indicator is correlated with the runoff volume.	The scenario with the lowest runoff volume (in/yr) gets a score = 5, and the one with the biggest runoff volume gets a score = 0. The other scenarios get their scores by interpolation between 0 to 5.
Building Energy Efficiency	acre	This indicator is correlated with the area of green roof (acre)[6]	The scenario with the biggest green roof area gets a score = 5, and the one with the smallest green roof area gets a score = 0. The other scenarios get their scores by interpolation between 0 to 5.
Avoided Water Treatment	gallons/day	This indicator is correlated with the volume of stormwater harvested and used	The scenario with the biggest harvested volume gets a score = 5, and the one with the lowest harvested volume gets a score = 0. The other scenarios get their scores by interpolation between 0 to 5.
Employment Opportunity	\$/yr	This indicator is correlated with the annual maintenance cost per technology	The scenario with the highest maintenance cost gets a score = 5 for the employment opportunity, and the one with the lowest maintenance cost gets a score = 0. The other scenarios get their scores by interpolation between 0 to 5.

1. (Jones et al., 2017)
2. (Getter et al., 2009; Jo & Mcpherson, 1995)
3. (Jones et al., 2017; Nowak et al., 2002)
4. (Oke, 1987)
5.(Lutzenhiser & Netusil, 2001; Shultz & Schmitz, 2008; Ward et al., 2008)
6.(Doshi et al., 2005)

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SUPPORTING MATERIAL FOR CHAPTER 4: CLASIC USER GUIDE

The following is user guide created for the CLASIC tool which walks user through how to navigate and best implement the tool.

CLASIC
User Guide

Purpose of CLASIC Tool

The CLASIC tool will serve as 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 will be hosted on the eRAMS platform so that it will be geographical information system (GIS) interfaced and include interaction with national databases to upload data for the modeled area.

CLASIC Tool Users

The expected users of the CLASIC tool include 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. It is anticipated that tool users would have a BS in a technical field, but not necessarily have experience with computer programming or database design. Users may have some experience with use of GIS, but this experience will not be required for use of the CLASIC tool.

CLASIC Tool Functionality

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

CLASIC Tool Outputs

There will be three categories of outputs 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.

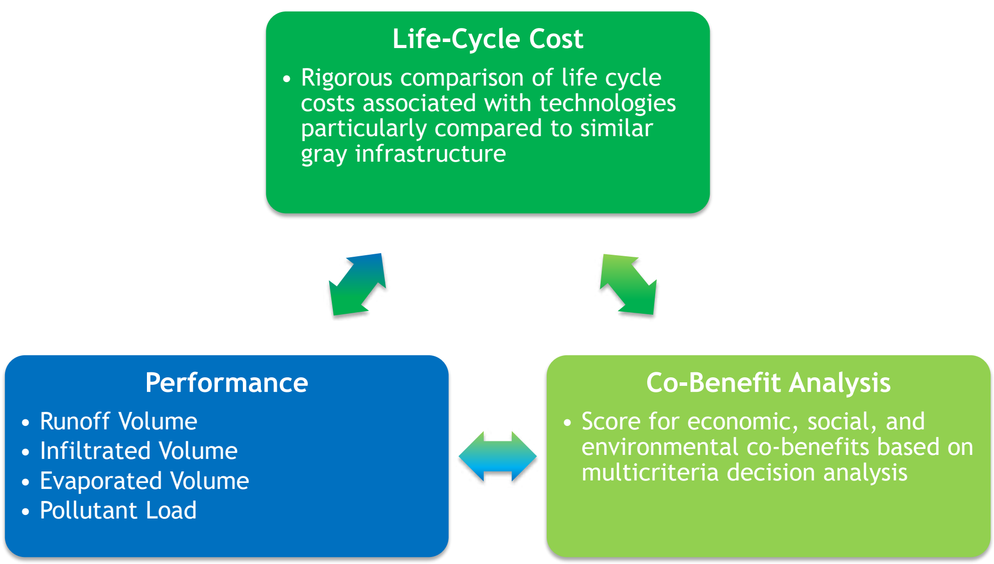

Figure 2: CLASIC Tool Outputs

Accessing & Navigating the CLASIC Tool

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).

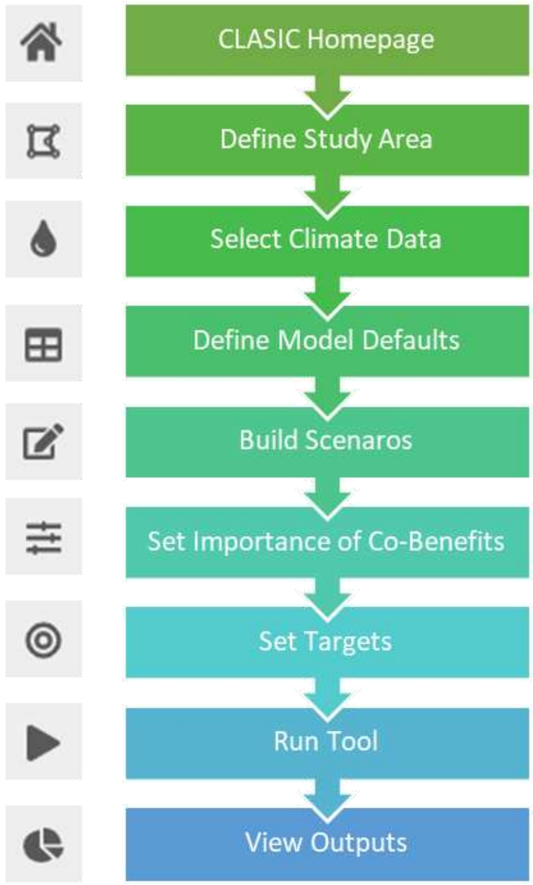

Figure 3: CLASIC Tool Steps

Note: The CLASIC tool is not compatible with Internet Explorer. Please use another browser.

Define Study Area 

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.

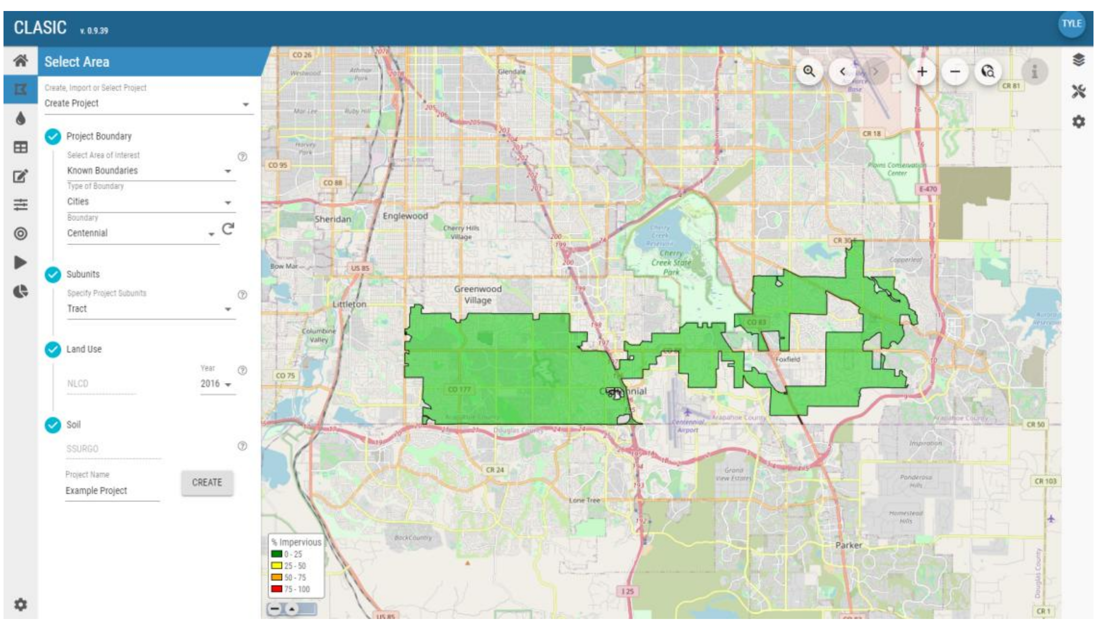

Figure 4: Define study area

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

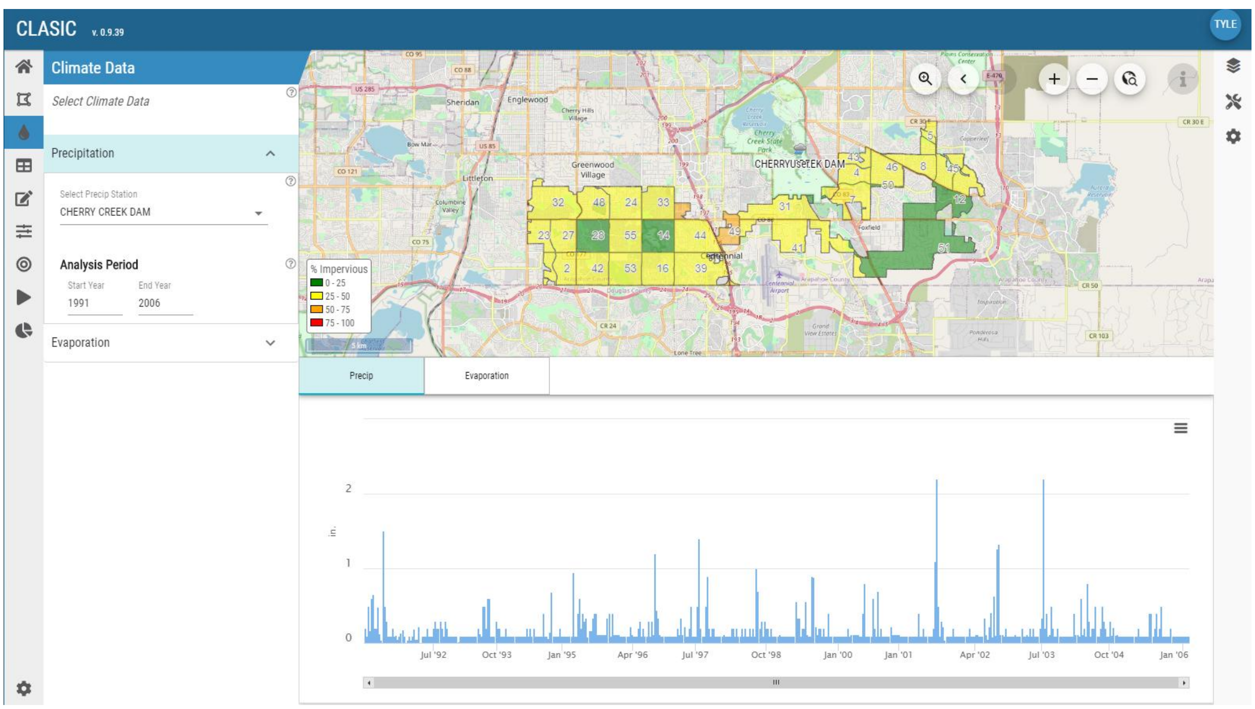

Figure 5: Selection of Climate Data Stations

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.

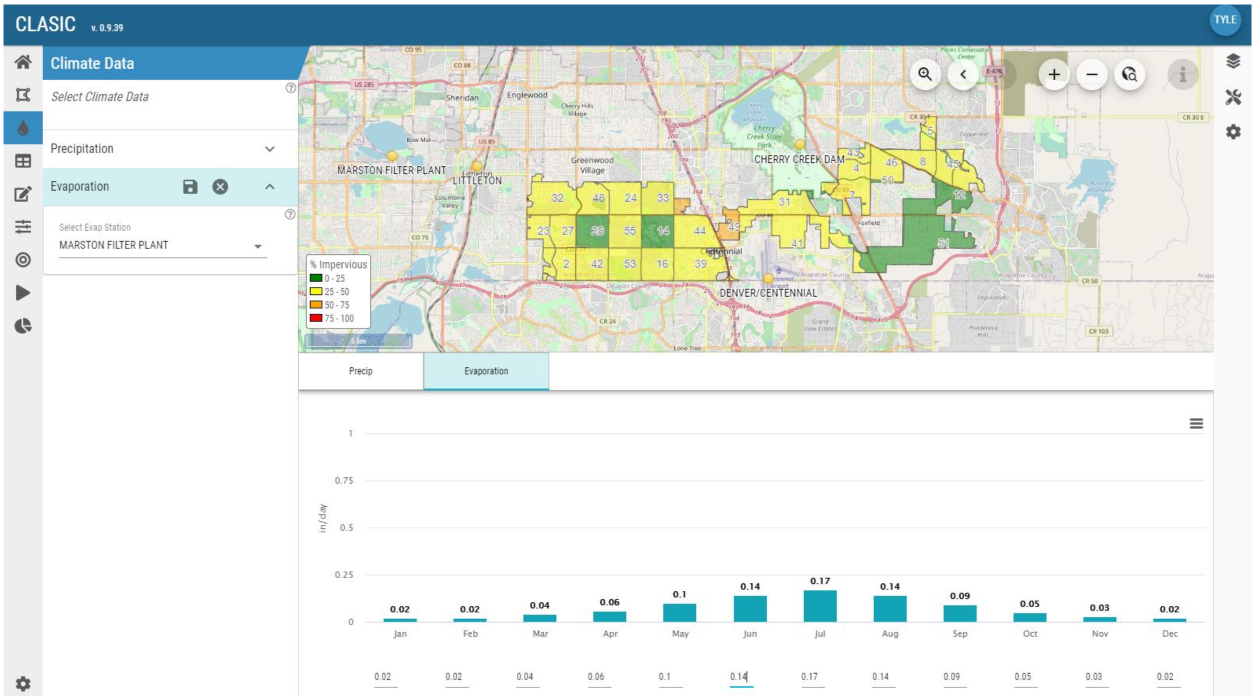

Figure 6: Editable Evaporation Data

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 disk icon; Figure 7). Changes may be reset to their default values using the revert button (see in Figure 7 next to Overland Flow Length).

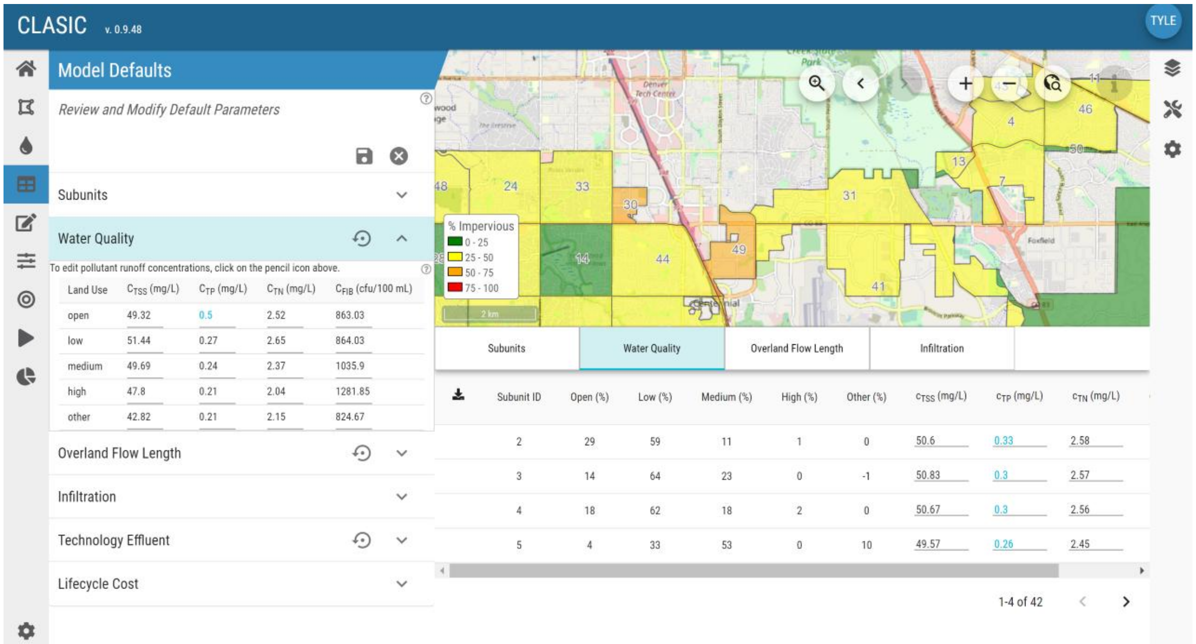

Figure 7: Option to Modify Default Parameters

- *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*.

Build Scenarios

1. 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).

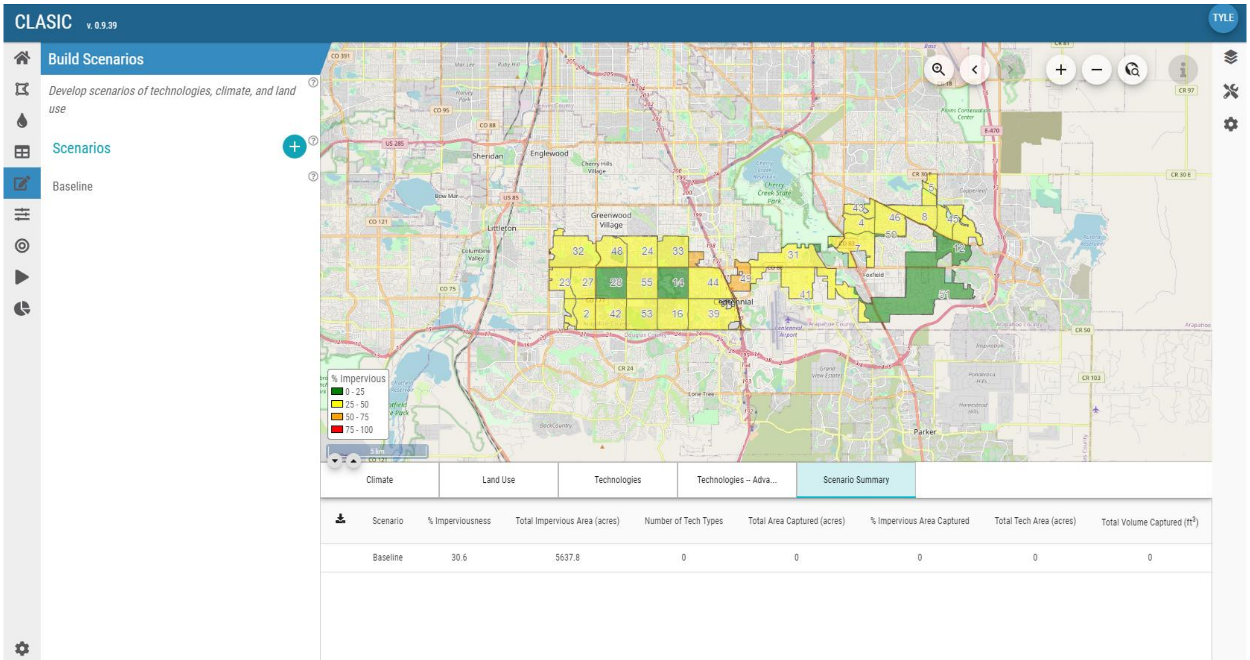

Figure 8: Adding Scenarios of Technologies, Land Use, and Climate

2. *Define Baseline Scenario*: 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 9 below).
        - *Define technology parameters:* 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.

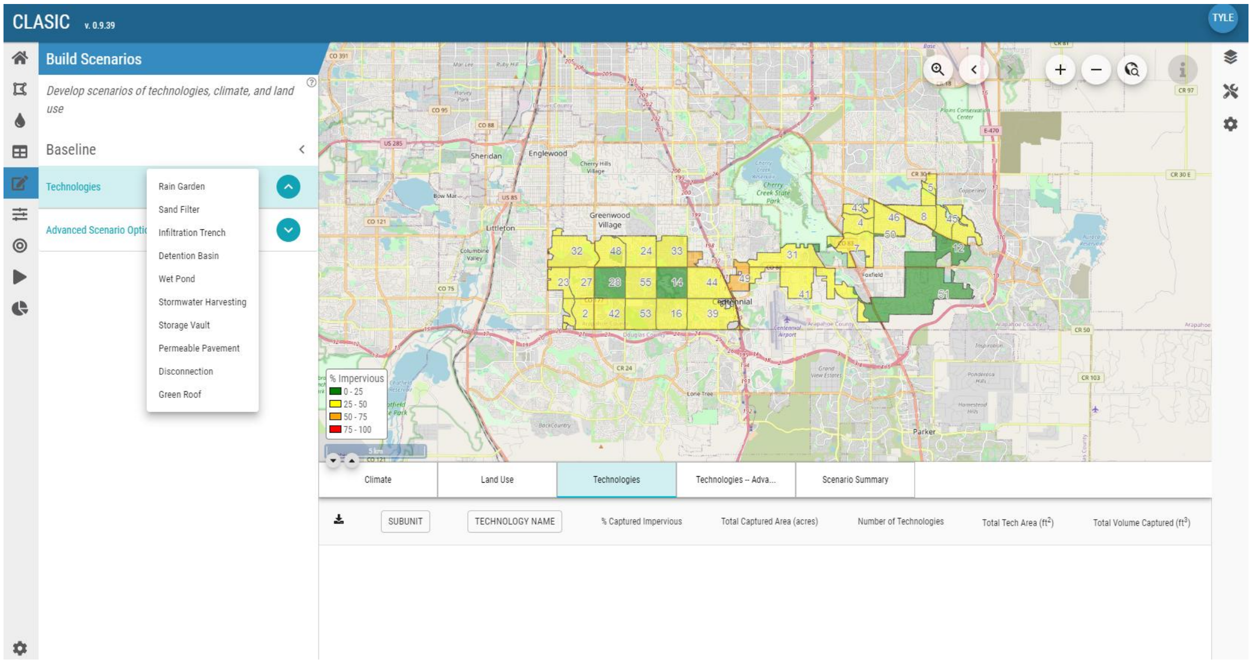

Figure 9: Selection of Technologies to Add to Scenario

- *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.
  - *All:* Technologies are added to all subunits.
  - *None:* Technologies are added to no subunits (use this selection to clear additions and restart)
  - *Select on Map:* Use the interactive map to select subunits for technology addition by clicking on the subunits to place or remove the technology.
  - *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

o Review table on right (Figure 10) 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.

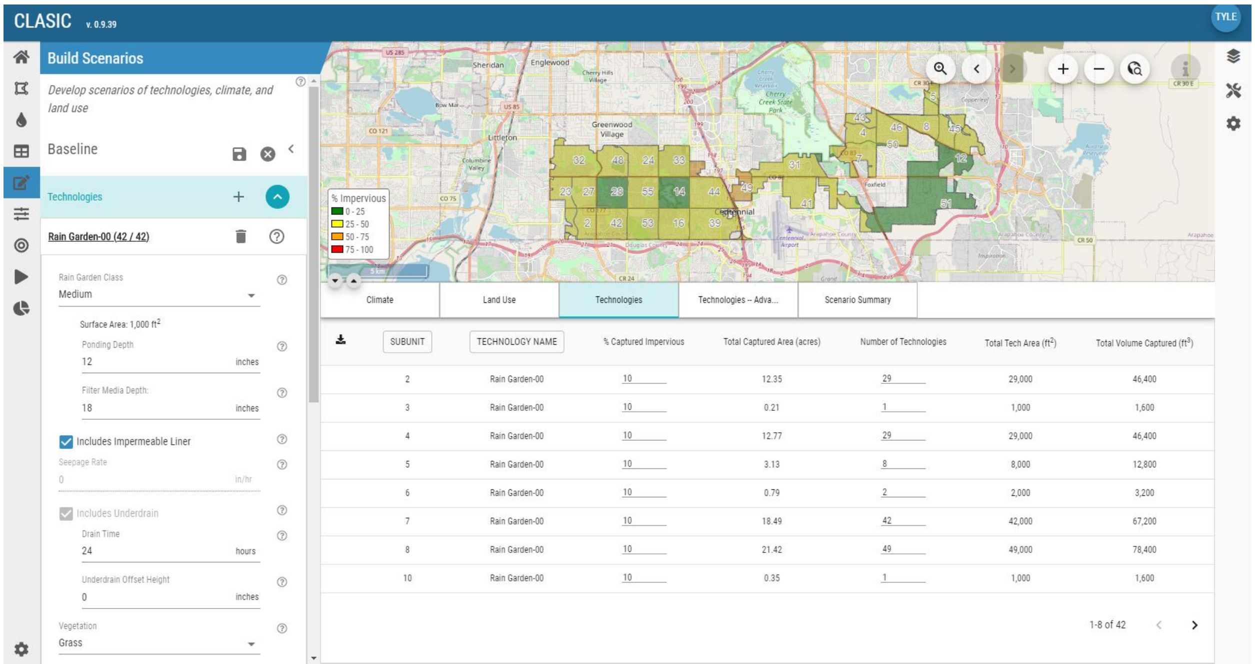

Figure 10: Summary Table of Added Stormwater Technologies

- *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.
    - *Cost modifications:* The construction, annual maintenance, or rehabilitation costs may also be edited for each technology type (Figure 11).

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 11: Modification of Costs for Technologies

3. *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.

4. *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 (Figure 12).

Table 1: Sources of Climate Data for Scenario Development

	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

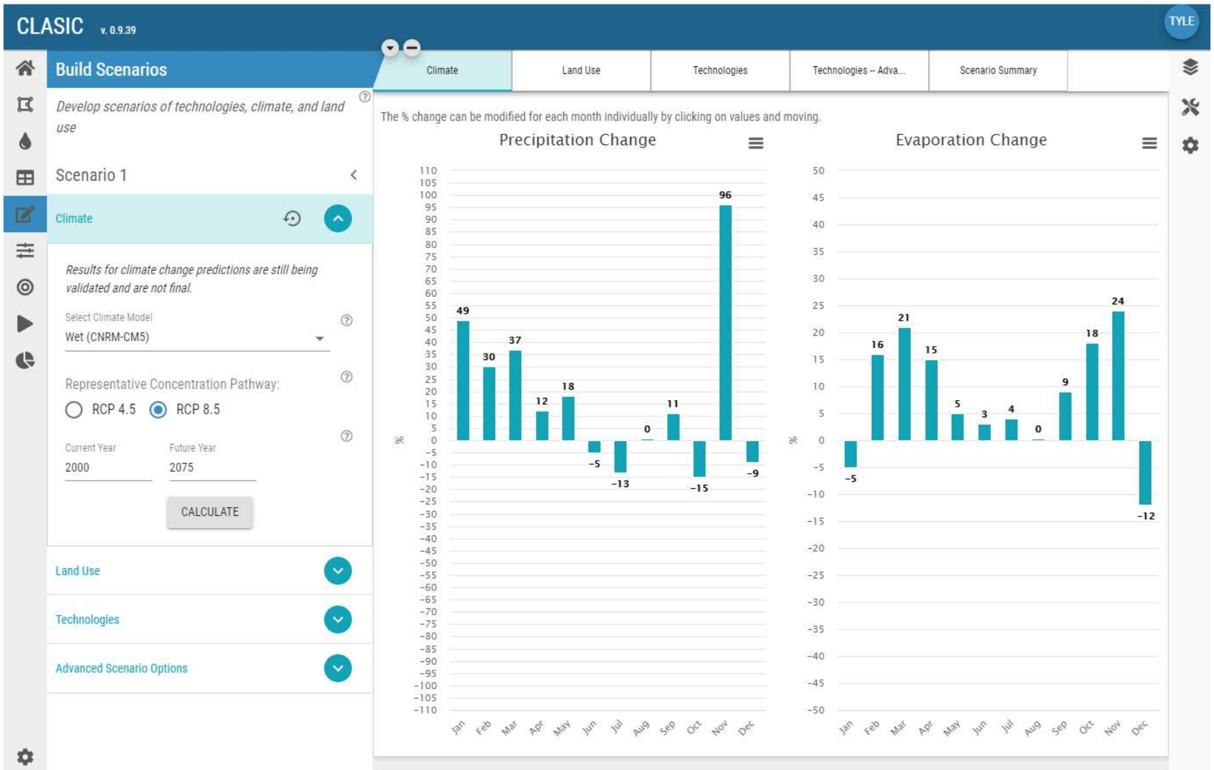

Figure 12: Modification of Climate for Scenarios

- *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 13).

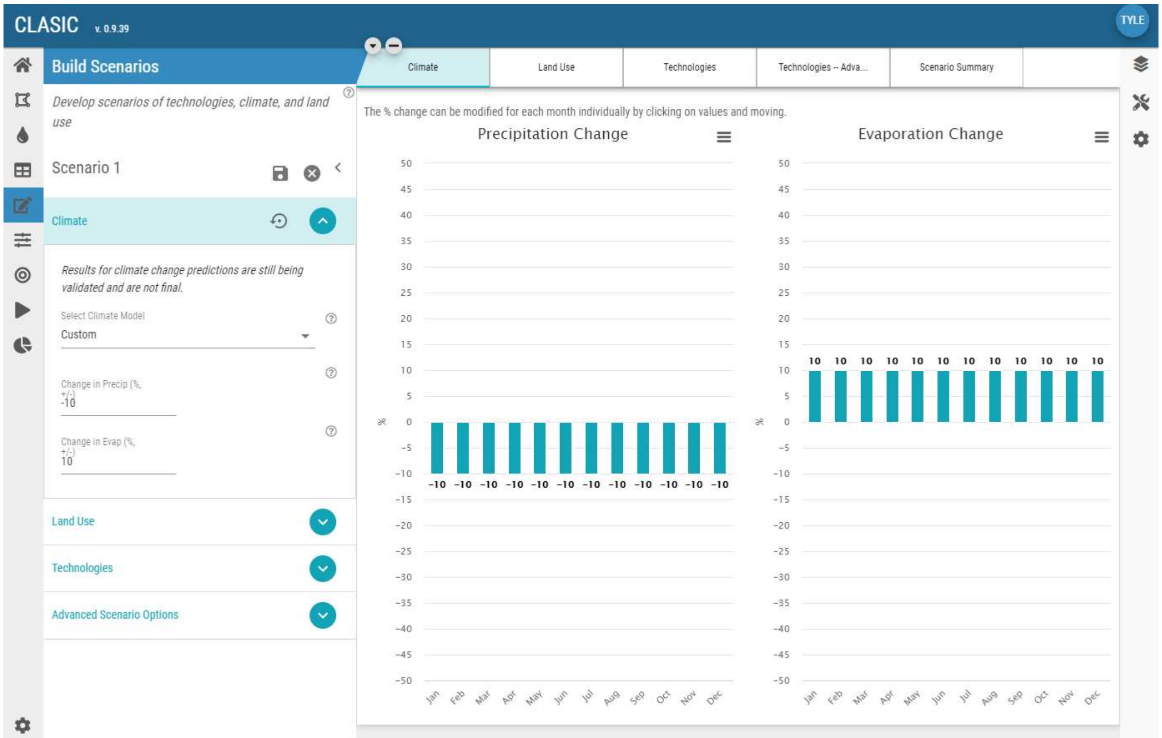

Figure 13: Manual Selection of Percentage Change in Monthly Precipitation and Evaporation for Climate Scenarios

5. *Modify land use for added scenarios:* Click to edit land use for a selected scenario (Figure 14). 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.

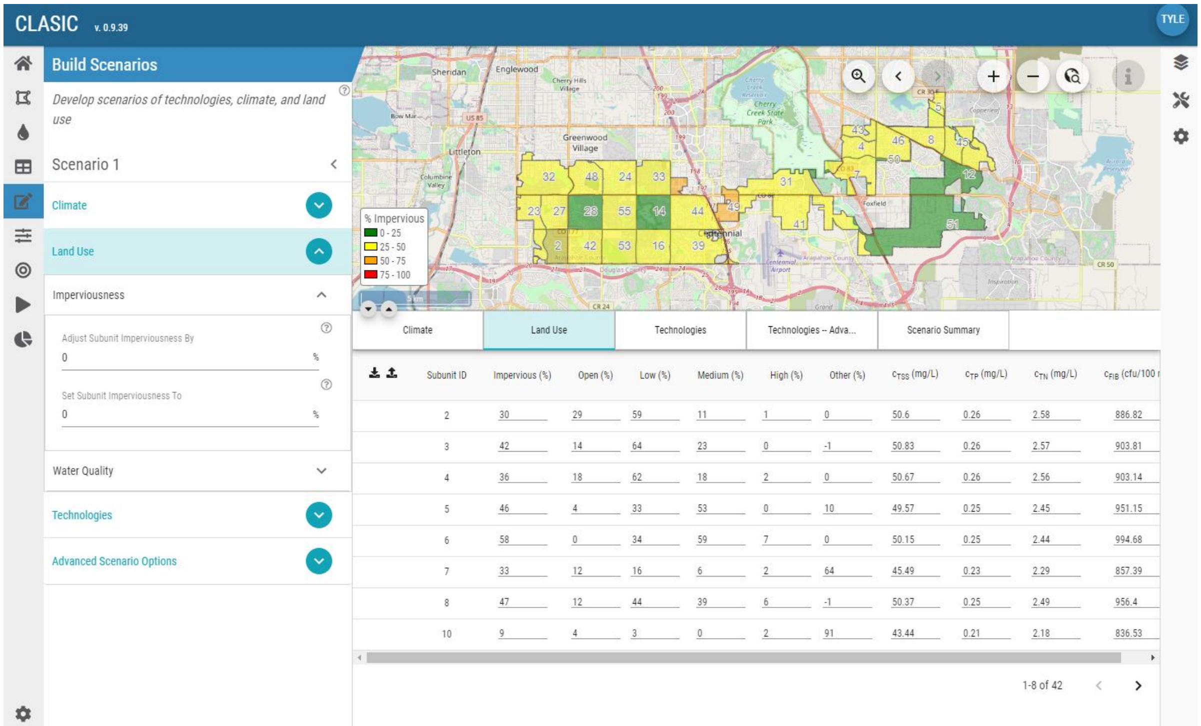

Figure 14: Table to Modify Impervious Area and Percentage of Land Cover Categories

6. *Add technologies:* See above instructions for adding technologies (under Step 2).
7. *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 15):

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.

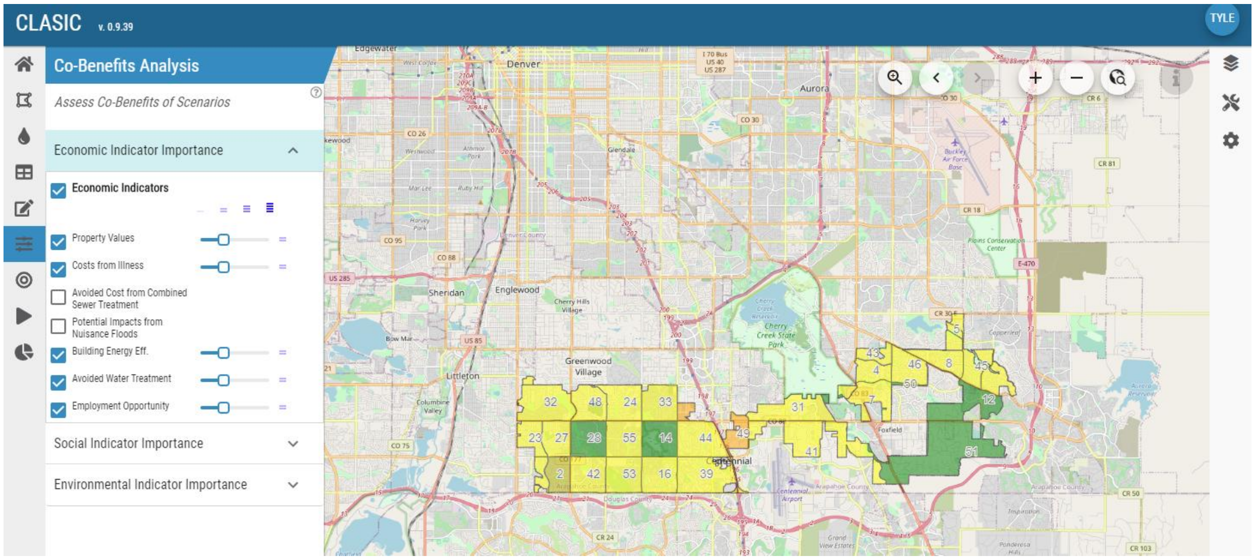

Figure 15: Selection of Importance Factors for Co-Benefit Indicators

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.

Set Targets

1. *Enter 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 (Figure 16).

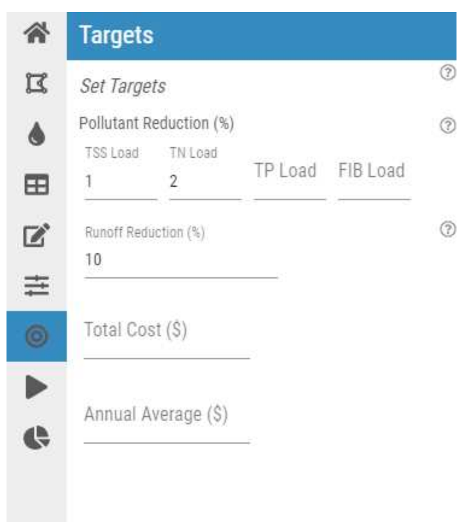

Figure 16: Setting Pollutant Removal and Cost Targets

- *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.
- *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.
- *Total Cost ($)*: Enter a total life cycle cost for the period that should not be exceeded.
- *Annual Average ($)*: Enter an average annual cost for the life cycle period that should not be exceeded.

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 17).
2. The first tab includes a summary of lifecycle cost, performance, and co-benefits (Figure 17). For more outputs in any of these three categories, click on the tab for which you would like to view more outputs. The question mark help button by each graphic provides guidance to interpret results.
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.

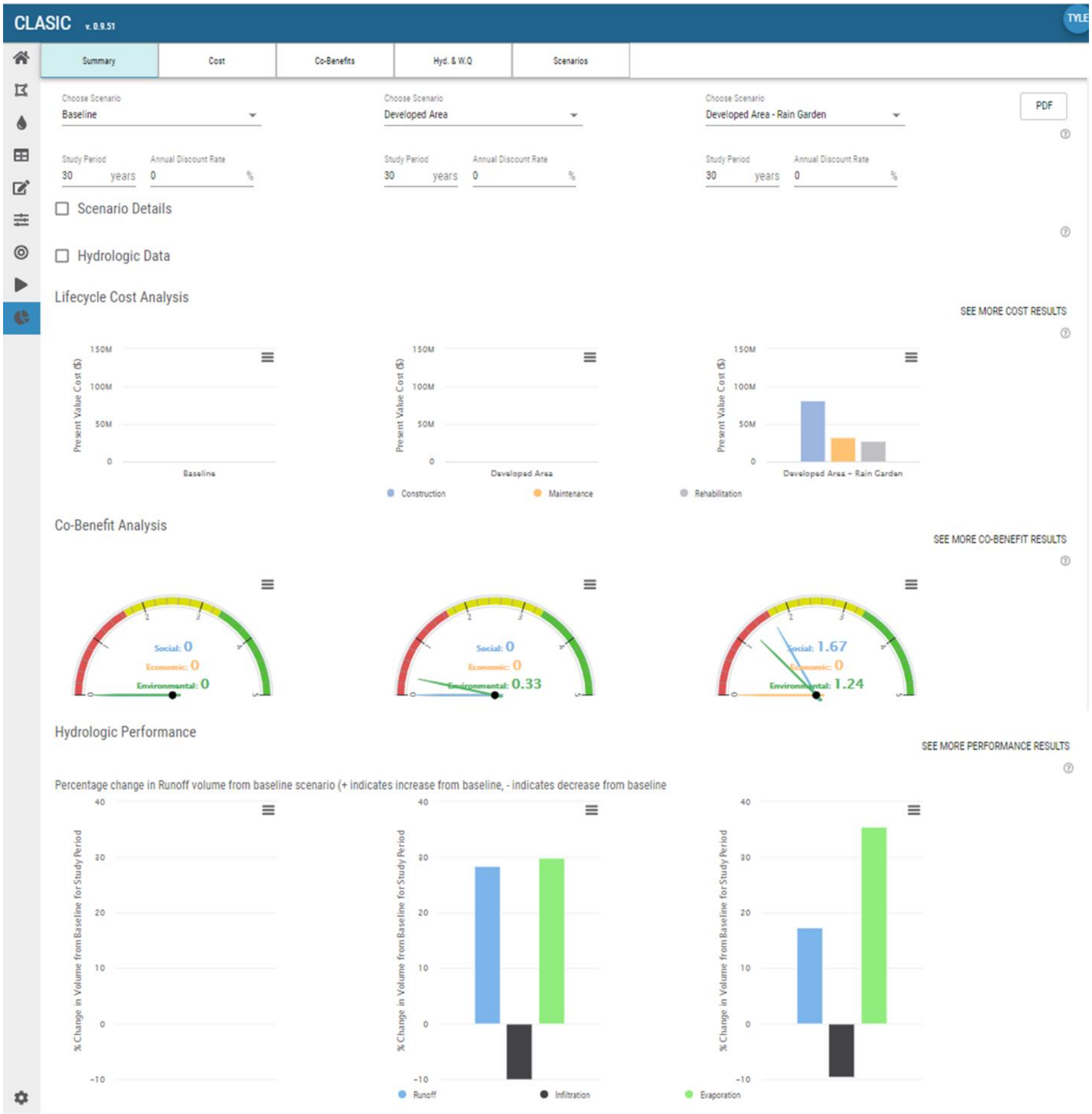

Figure 17: Graphical Outputs Summarizing Performance for Cost, Co-Benefits, and Hydrology

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