Holistic Watershed Management for Existing and Future Land Use Development Activities: Opportunities for Action for Local Decision Makers: Phase 2 – Flow Duration Curve Application Modeling (FDC 2A Project)

SUPPORT FOR SOUTHEAST NEW ENGLAND PROGRAM (SNEP) COMMUNICATIONS STRATEGY AND TECHNICAL ASSISTANCE

Task 5: Opti-Tool Enhancements: Green Roofs and Temporary Run-off Storage with IC Disconnection

March 17, 2021

Prepared for:

U.S. EPA Region 1

Prepared by:

Paradigm Environmental

Great Lakes Environmental Center

Blanket Purchase Agreement: BPA-68HE0118A0001-0003
Requisition Number: PR-R1-20-00322
Order: 68HE0121F0052

Table of Contents

1. Introduction 2
2. Green Roof 2
3. IC Disconnection with storage 6
4. IC Disconnection without Storage 11
5. Summary 13
6. References 14

Figures

Figure 2-1. Conceptual schematic of a typical green roof system as represented in the Opti-Tool. 3
Figure 2-2. Green roof BMP setup windows within the Opti-Tool. 5
Figure 3-1. Typical residential rain barrel application highlighting key geometry parameters. 6
Figure 3-2. Typical cistern release curve used in Opti-Tool. 7
Figure 3-3. Rain barrel setup window within the Opti-Tool. 9
Figure 3-4. Cistern setup window within the Opti-Tool. 10
Figure 3-5. Cistern release curve input window within the Opti-Tool. 10
Figure 4-1. Impervious disconnection schematic. 11
Figure 4-2. IC Disconnection BMP setup window within the Opti-Tool. 12

Tables

Table 2-1. Suggested parameter values for representation of green roofs in Opti-Tool 3
Table 3-1. Suggested parameter values for representation of IC disconnect with rain barrel storage in Opti-Tool 7
Table 3-2. Suggested parameter values for representation of IC disconnect with cistern storage in Opti-Tool 8
Table 4-1. Suggested parameter values for representation of IC disconnect without storage in Opti-Tool. 12

1. INTRODUCTION

This memorandum outlines four new green infrastructure stormwater control measures (GI SCM), incorporated into the Opti-Tool to support management alternative analyses involving disconnection of impervious cover (IC). The Opti-Tool was configured to simulate (1) green roof technologies (2) IC disconnection with temporary runoff storage (i.e., rain barrels or cisterns), and (3) IC disconnection without temporary storage. Schematics of these GI SCMs are presented to illustrate the key simulation processes. This memorandum is organized into the following sections:

- Green Roofs (Section 2)
- IC Disconnection with Temporary Storage (Section 3)
- IC Disconnection without Temporary Storage (Section 4)

2. GREEN ROOF

A green roof GI SCM was added as an option for modeling the conversion of conventional roofs to green roofs as a method for impervious disconnection. Green roofs provide benefits including runoff peak and volume reduction as well as water quality improvement under well-designed systems. They also produce several other benefits beyond stormwater including improvement of building energy efficiency, creation of quality habitat, and reduction in heat fluxes that mitigate the effects of urban heat islands. The Opti-Tool green roof CSM focuses solely on modeling the stormwater processes and does not include explicit representations of these secondary benefits. However, outputs from the Opti-Tool may be used to support calculations outside of the model to estimate these secondary benefits.

Figure 2-1 presents a conceptual diagram of the key processes occurring with the green roof system. The processes are grouped into four layers (far left) to better organize their relationship to the overall water budget and make links to key parameters in the Opti-Tool. External water balance inputs and outputs occur on the top vegetation layer. The growth layer represents the soil media in which the plants grow. This layer includes the plant roots and has available pore storage for the retention of stormwater. The drainage layer represents an underdrain system that ensures the roof can properly drain when the growth layer becomes saturated. Impermeable roof decking sits below the drainage layer and acts as a barrier between the green roof and the building below it. The roof deck is represented by a 0.0 inch/hour background infiltration rate which ensures that all water exiting the drainage layer continues downstream as additional runoff.

Based on the schematic in Figure 2-1, Table 2-1 presents a summary of the default parameter values for representing the key processes of green roof GI SCMs within Opti-Tool. The summary presents parameters related to each of the key processes grouped by layer. The green roof setup windows within Opti-Tool are shown in Figure 2-2. The *Green Roof* footprint can be optimized using the LENGTH as a decision variable in Opti-Tool. The Opti-Tool does not simulate the rainfall but instead uses the pre-simulated runoff time series as boundary conditions. To simulate the direct rainfall on the BMP footprint, the user has to add the BMP surface area as an impervious HRU area to the BMP drainage area. For example, if 50% of the rooftop area is converted to the *Green Roof* and the remaining 50% of the rooftop area is draining to the *Green Roof* then the drainage area for the *Green Roof* will be 100% of the rooftop area.

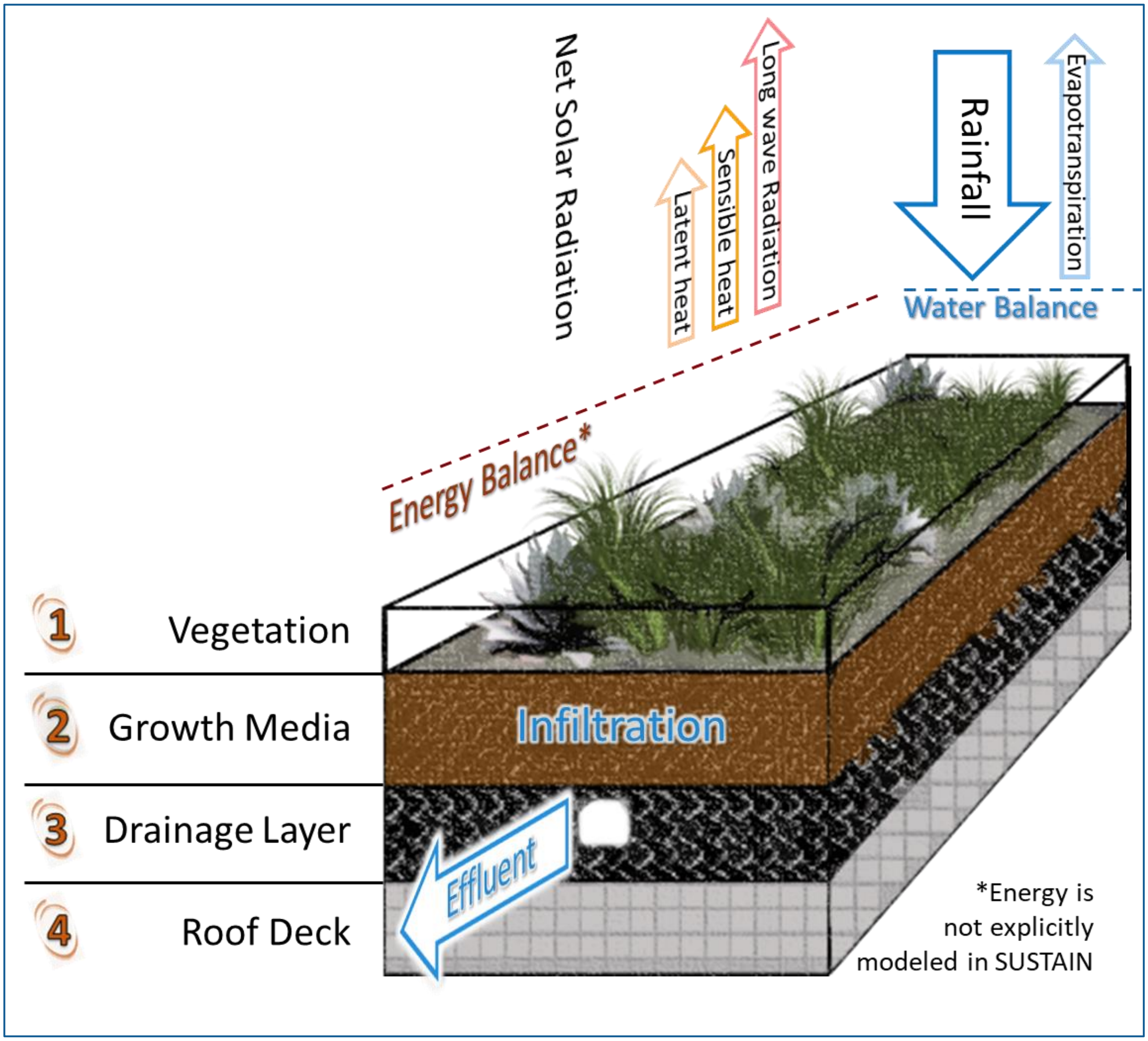

Figure 2-1. Conceptual schematic of a typical green roof system as represented in the Opti-Tool.

Table 2-1. Suggested parameter values for representation of green roofs in Opti-Tool

Layer	Parameter	Description	Value(s)	Units
1. Vegetation	FOOTPRINT	Roof area available	Varies	ft^2
	AVEG	Holtan Vegetative Parameter	1	--
	GI	Holtan Growth Index	Seasonal (0.1-1.0)	--
	ETMULT	ET Multiplier [1]	1.0	--
	WEIRH	Weir Height for Overflow	0.1	ft
2. Growth Media	SDEPTH	Soil Media Depth [2]	1	ft
	POROSITY	Media Porosity [3]	78	%
	FINFILT	Media Infiltration Rate [3]	51.8	in/hr
3.	UDDEPTH	Drainage Depth [4]	0.1	ft

Layer	Parameter	Description	Value(s)	Units
Drainage Layer	VOID	Void Space [5]	50	%
	QUALPCTREM	Treatment Efficiency (TSS) [6]	88.7	%
		Treatment Efficiency (TN) [6]	55	%
		Treatment Efficiency (TP) [6]	-248	%
		Treatment Efficiency (TZn) [6]	70	%
		Treatment Efficiency (*E. coli)* [6]	10.8	%
4. Roof Deck	INFILT	Native soil infiltration	0.0	In/hr
--	COST	Unit-volume cost of Green Roof [7]	70	$/ft^3

1. Recommended Penman Monteith-based ASCE standard reference ET equation (Marasco et al., 2014).
2. Soil depths can vary between intensive and extensive applications (Razzaghmanesh & Beecham, 2014).
3. Media porosity and infiltration rate (Omni Ecosystems Green Roof).
4. Drainage layer depth for extensive green roof application
5. Typical void space in the drainage media (Baryła et al., 2018).
6. Treatment efficiency is reported from a monitoring study on two surfaces of a roof in Toronto. The conventional surface is a 131 m^2 shingled, modified bitumen roof. The 241 m^2 green roof is vegetated with wildflowers. The 14cm growth medium is composed of crushed volcanic rock, compost, blonde peat, cooked clay, and washed sand (Seters et al., 2009).
7. Average cost based on Omni Ecosystems Green Roof pricing matrix, 2018.

Infiltration through the growth media is governed by the Holtan infiltration method as described in the following equation (USEPA 2009, USEPA 2012):

$$F = GI * AVEG * (\text{Soil Media Storage})^{1.4} + FINFILT$$

Where:

F is the final infiltration rate in inches per hour
GI is the growth index that varies monthly
AVEG is the Vegetative A parameter
FINFILT is the saturated infiltration rate in inches per hour, and
Soil Media Storage is the available storage in inches computed at each model time step

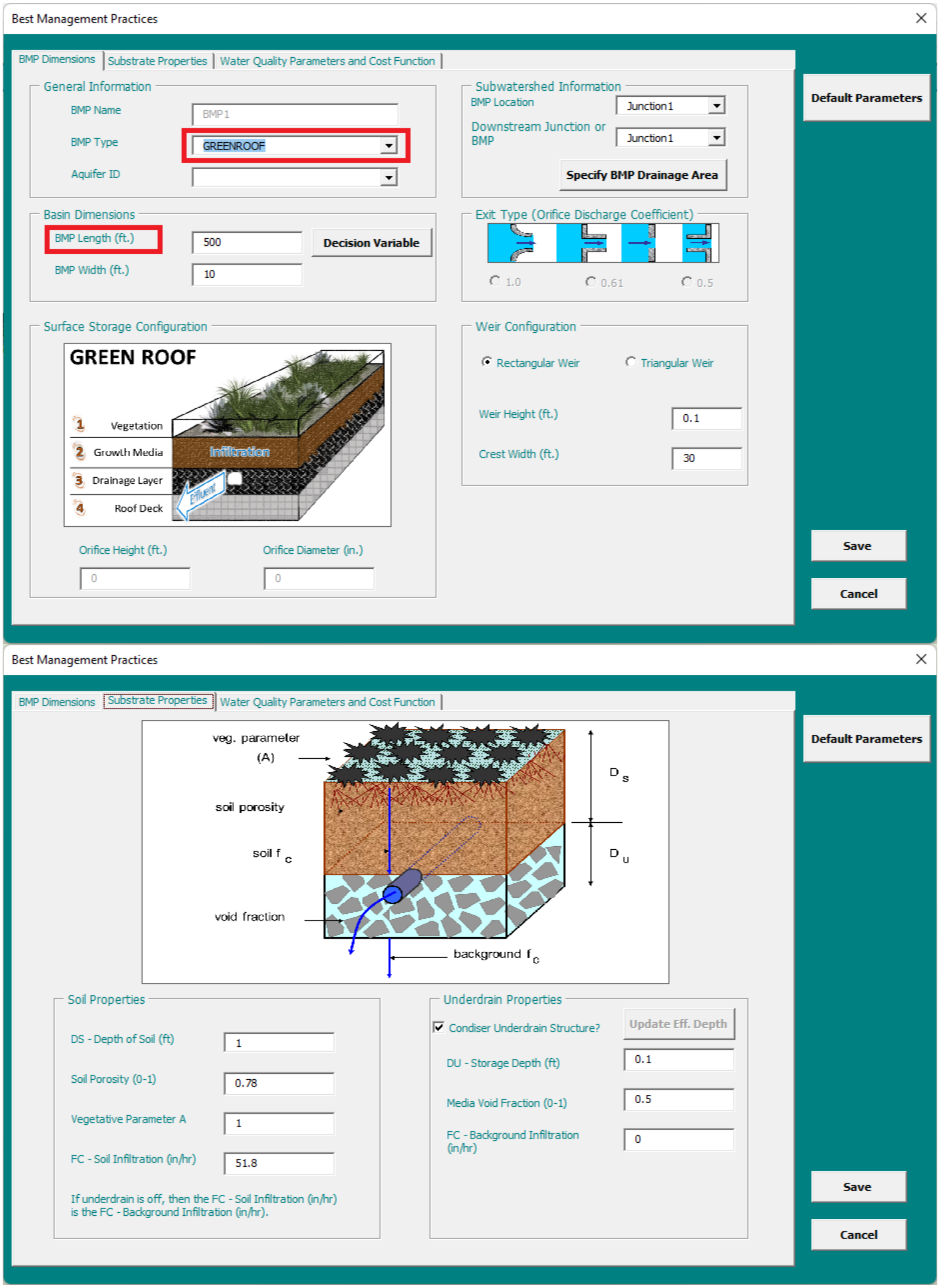

Figure 2-2. Green roof BMP setup windows within the Opti-Tool.

3. IC DISCONNECTION WITH STORAGE

To model IC disconnection where temporary storage is available, rain barrel and cistern BMPs were added to the Opti-Tool. These BMPs include a basic tank volume for the storage of stormwater. IC runoff from roofs, or other impervious surfaces, when possible, are routed to the tank. During runoff events, available storage within the tank will be filled; if the tank storage is exceeded, the additional volume is routed downstream as untreated runoff. The difference between rain barrels and cisterns within Opti-Tool is based on how the stored water is consumed. For rain barrels, the stored water is drained to represent non-portable water use after a preset user-defined duration of dry days. Stored water within cisterns is drained based on a user-defined per-capita consumption curve and the number of people. These uses can be routed out of the system to represent a consumptive use and do not contribute to the untreated runoff volume.

IC disconnection simulates the storage and processes associated with a rain barrel and cistern features which typically receive runoff from residential roofs. Key process parameters include the volume of the available storage, the height of the tank, the size of the contributing area that the storage is designed to receive, and parameters related to the draw-down and usage of captured water including the hose orifice height and diameter. Draw-down of captured water is necessary to ensure that storage is again made available to capture subsequent storms. These BMPs are assumed to be fully enclosed and, therefore, do not simulate evapotranspiration (ET). A typical residential rain barrel application highlighting some key geometric parameters is presented in Figure 3-1. A typical cistern release curve is shown in Figure 3-2.

Table 3-1 and Table 3-2 present the proposed default values for IC disconnection using rain barrels and cisterns, respectively, as temporary storage, including the geometry parameters highlighted in Figure 3-1. Typically, costs associated with implementing rain barrels include the cost of the actual rain barrel and any costs needed for proper installation. Since residential rain barrels are often installed by the homeowner or through community-group or local government outreach programs, including installation costs is likely not necessary. The rain barrel and cistern setup windows within the Opti-Tool are shown in Figure 3-3 and Figure 3-4. The cistern's default release curve values can be updated through the user interface shown in Figure 3-5.

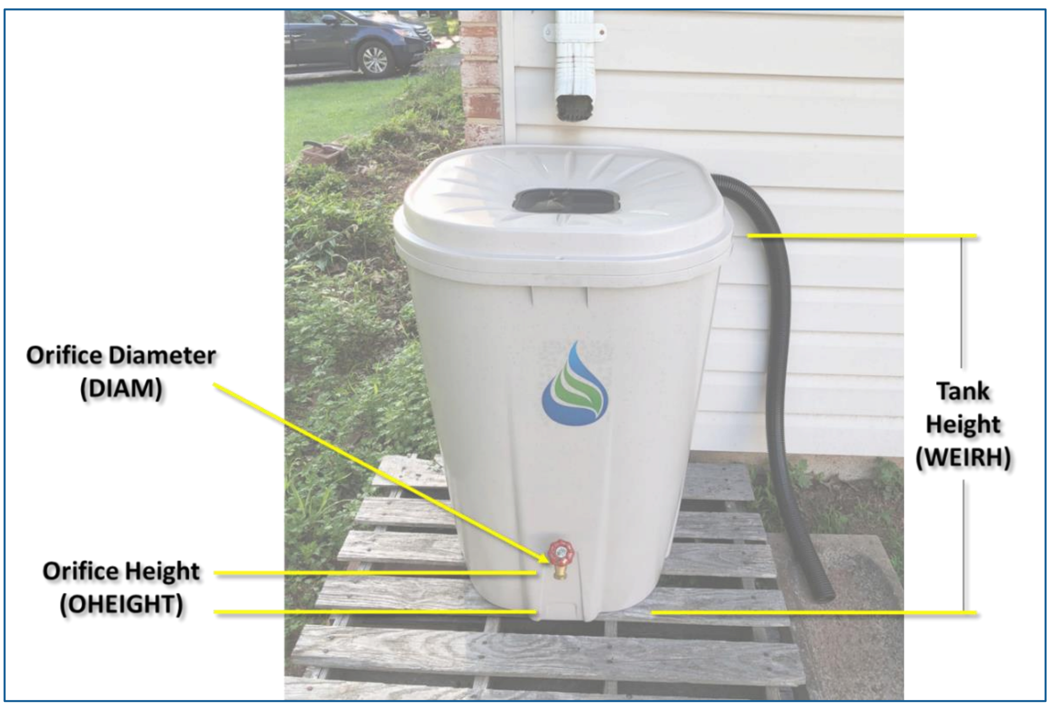

Figure 3-1. Typical residential rain barrel application highlighting key geometry parameters.

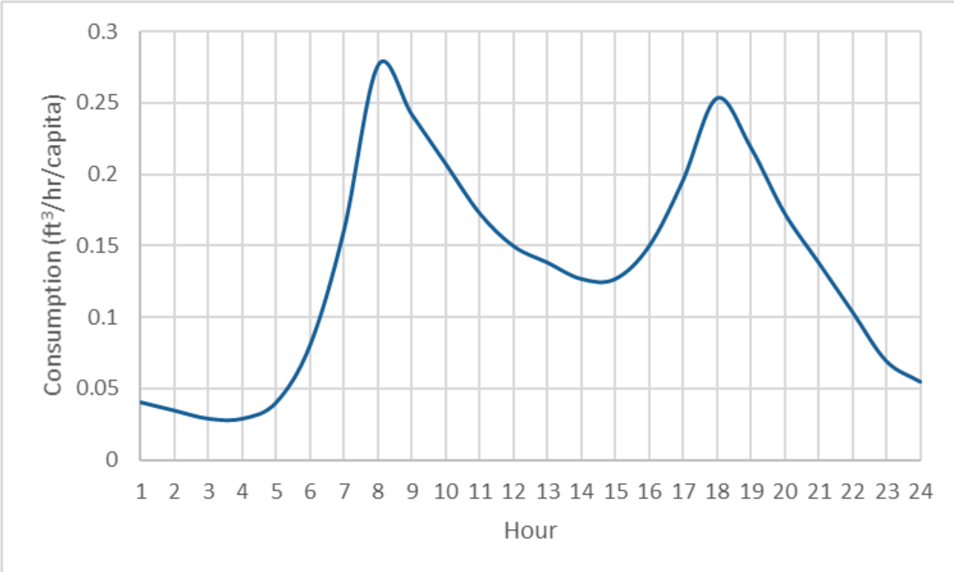

Figure 3-2. Typical cistern release curve used in Opti-Tool.

Table 3-1. Suggested parameter values for representation of IC disconnect with rain barrel storage in Opti-Tool

Parameter	Description	Default Value	Units
VOLUME	Storage volume of rain barrel	50	gallons
WEIRH	Total height of rain barrel	2.5	feet
DIAM	Diameter of the release orifice	1	inches
OHEIGHT	Height of the release orifice	0.5	feet
DDAREA	Maximum designed contributing area	Varies based on the rain barrel capacity	acres
DDAYS	Number of dry days before release begins	3	days
ETMULT	ET Multiplier	0.0	--
DECAY	Pollutant Decay Rate (TSS)	0.0	1/day
	Pollutant Decay Rate (TN)	0.0	1/day
	Pollutant Decay Rate (TP)	0.0	1/day
	Pollutant Decay Rate (TZn)	0.0	1/day
	Pollutant Decay Rate (*E. coli*)	0.0	1/day
NUMUNIT [1]	Number of Rain Barrels	Varies	--
COST [2]	Cost of Rain Barrel + Disconnection	216	$/unit (50 gallons)

1. The number of rain barrels (NUMUNIT) is a decision variable.
2. Unit Cost ($/50 gallon) (Ref: https://www.lid-stormwater.net/raincist_cost.htm).

Rain barrels normally are not designed to meet the water quality objectives, so the pollutant decay rates default to zero as a placeholder in the Opti-Tool and those can be easily updated if the observed data is available.

Table 3-2. Suggested parameter values for representation of IC disconnect with cistern storage in Opti-Tool

Parameter	Description	Default Value	Units
VOLUME	Storage volume of the cistern	200	gallons
WEIRH	Total height of the cistern	4	feet
DIAM	Diameter of the release orifice	1	inches
OHEIGHT	Height of the release orifice	0.5	feet
DDAREA	Maximum designed contributing area	Varies based on the cistern capacity	acres
PEOPLE	Number of people served by a cistern	3	--
ETMULT	ET Multiplier	0.0	--
DECAY	Pollutant Decay Rate (TSS)	0.0	1/day
	Pollutant Decay Rate (TN)	0.0	1/day
	Pollutant Decay Rate (TP)	0.0	1/day
	Pollutant Decay Rate (TZn)	0.0	1/day
	Pollutant Decay Rate (*E. coli*)	0.0	1/day
NUMUNIT [1]	Number of cisterns	Varies	--
COST [2]	Cost of cistern + Disconnection	225	$/unit (200 gallons)

1. The number of cisterns (NUMUNIT) is a decision variable.
2. Unit Cost ($/200 gallon) (Ref: https://www.lid-stormwater.net/raincist_cost.htm).

Cisterns normally are not designed to meet the water quality objectives, so the pollutant decay rates default to zero as a placeholder in the Opti-Tool and those can be easily updated if the observed data is available.

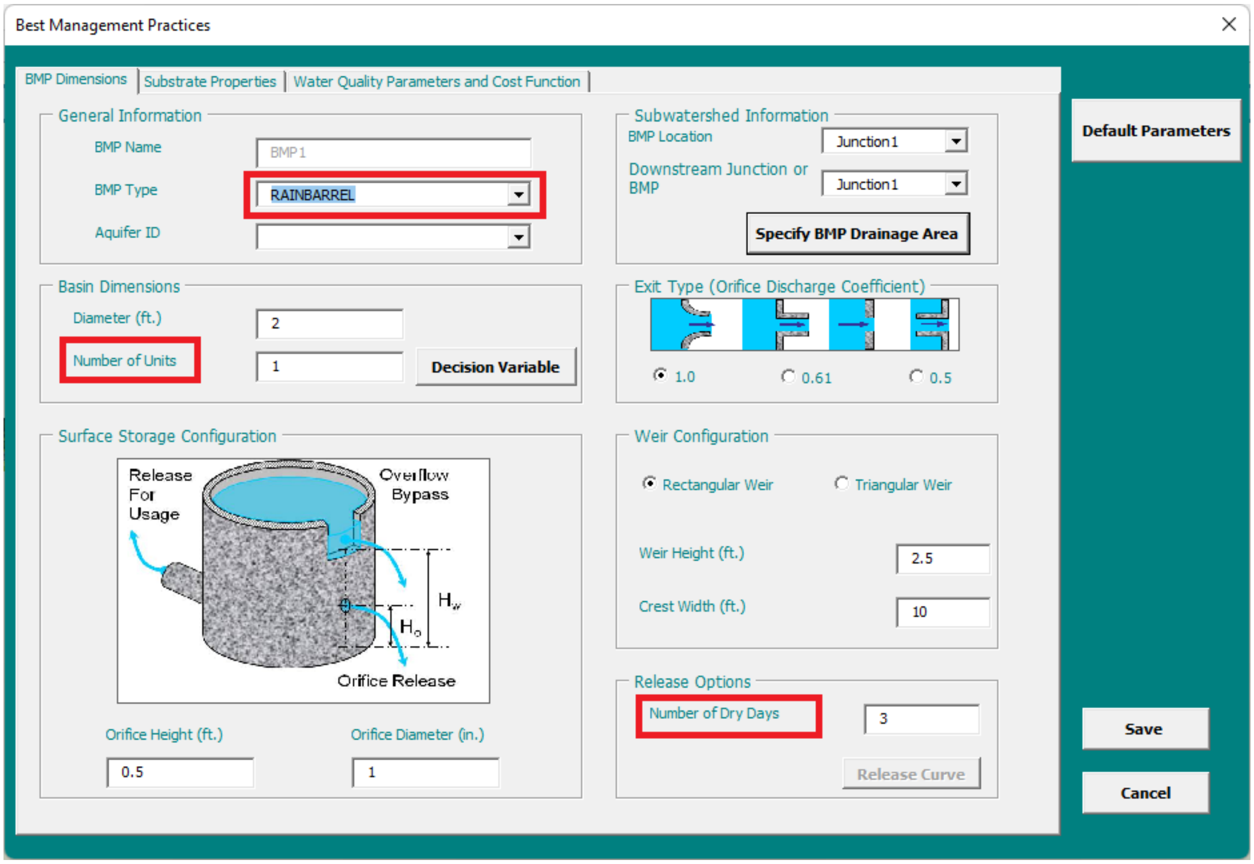

Figure 3-3. Rain barrel setup window within the Opti-Tool.

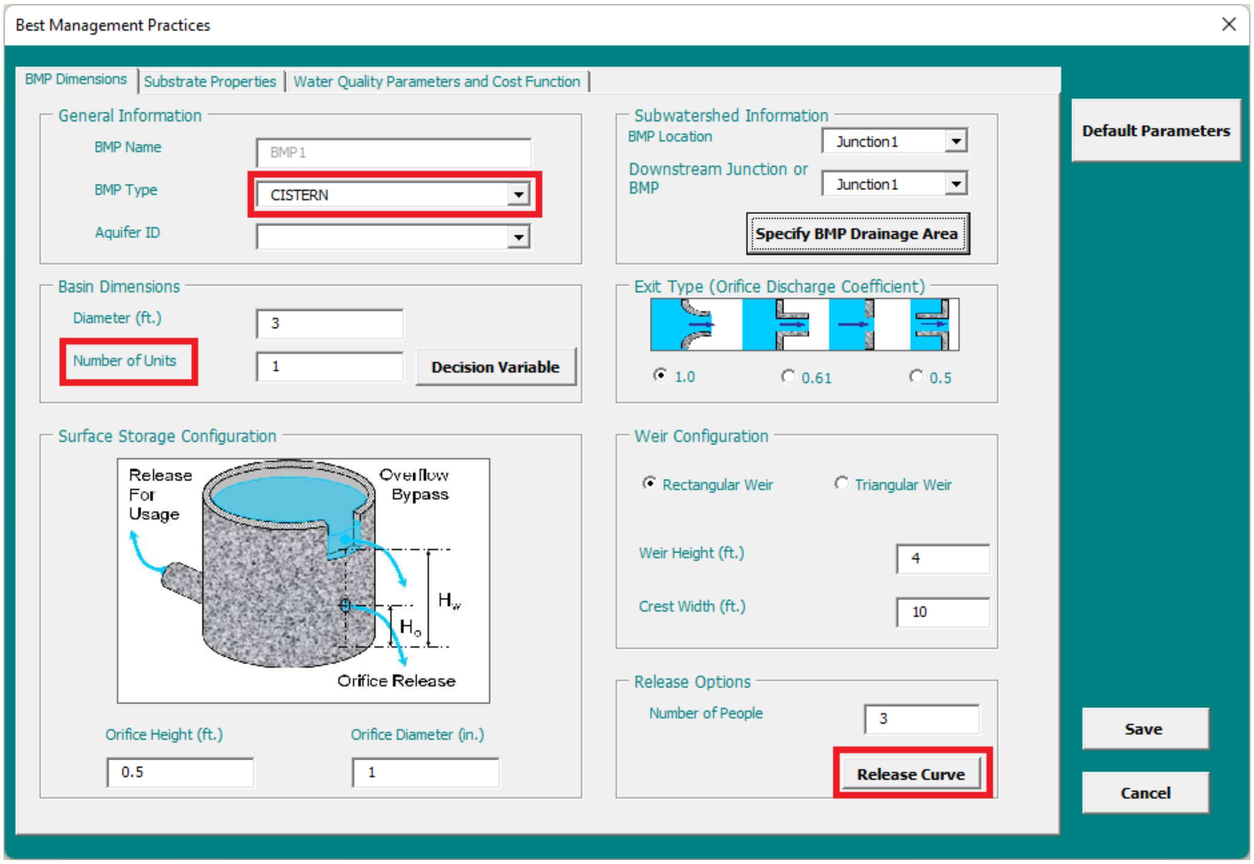

Figure 3-4. Cistern setup window within the Opti-Tool.

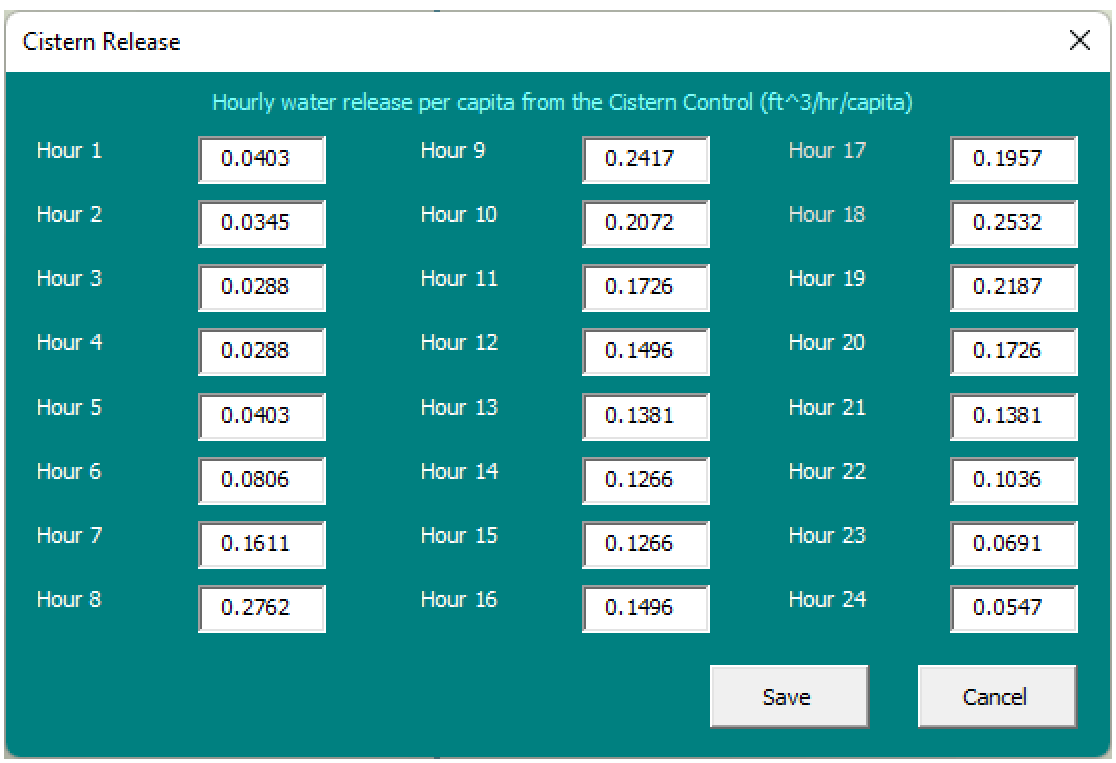

Figure 3-5. Cistern release curve input window within the Opti-Tool.

4. IC DISCONNECTION WITHOUT STORAGE

To model IC disconnection where temporary storage is not used, routing over a pervious land segment was added as a BMP to the Opti-Tool. A nonlinear reservoir routing algorithm is applied to route the surface runoff from the impervious cover to the pervious area where depression storage and infiltration reduce the volume of runoff contributed by the impervious cover.

This approach approximates reality where the runoff from the impervious area is routed to and simulated on the pervious area. The runoff from the disconnected impervious area is captured by the modeled pervious land through infiltration and surface storage. The pervious land does not simulate additional ET since surface runoff already accounts for it in the HRU time series as boundary conditions. Surface runoff occurs only when the surface water depth exceeds the maximum surface storage depth, where surface runoff is calculated using Manning's equation and infiltration rate is calculated using the Horton infiltration method.

Figure 4-1 presents a plan view schematic of impervious area routing to an adjacent pervious area where key overland flow parameters are used to simulate storage and infiltration processes. Table 4-1 presents the recommended default values for representing the pervious land segment used for disconnecting IC. Typically, the cost associated with implementing IC disconnection to pervious land is limited only to the physical disconnection process from the MS4. Since homeowners can typically handle this process with limited technical guidance, these capital costs may be negligible. However, the cost associated with conveying the runoff from the impervious cover as a sheet flow or a level spreader could be expressed as a per linear foot (LENGTH) of pervious area perpendicular to the flow path as shown in Figure 4-1. Figure 4-2 shows the IC Disconnection BMP setup window within the Opti-Tool.

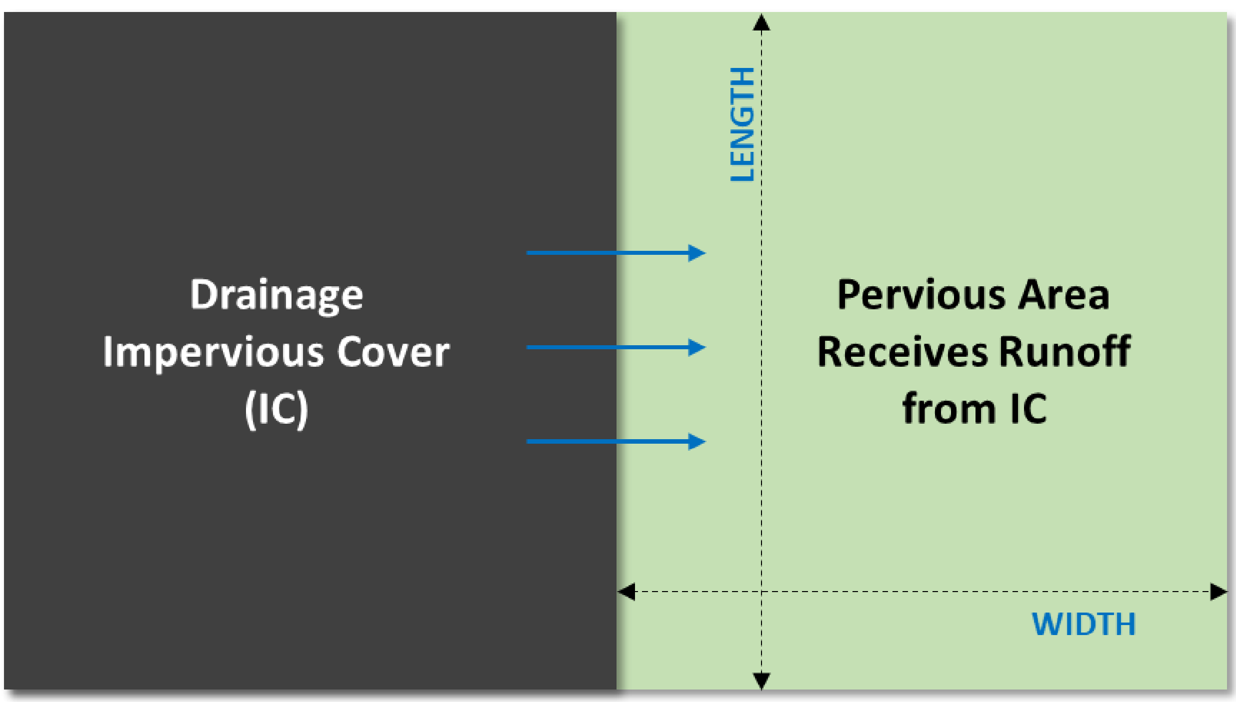

Figure 4-1. Impervious disconnection schematic

Table 4-1. Suggested parameter values for representation of IC disconnect without storage in Opti-Tool

Parameter	Description	Default Value	Units
LENGTH [1]	Length of the pervious area over which flow occurs (perpendicular to the flow path)	Varies	feet
WIDTH	Width of the pervious area over which flow occurs (flow length)	Varies	feet
DSTORAGE	Surface depression storage of the pervious area	0.15	inches
SLOPE	Overland slope of the pervious area	0.01	feet/feet
MANNING_N	Overland Manning's roughness coefficient	0.13	--
SAT_INFILT	Saturated infiltration rate	Varies based on the hydrologic soil group	inch/hour
DECAY	Pollutant Decay Rate (TSS)	0.0	1/day
	Pollutant Decay Rate (TN)	0.0	1/day
	Pollutant Decay Rate (TP)	0.0	1/day
	Pollutant Decay Rate (TZn)	0.0	1/day
	Pollutant Decay Rate (*E. coli*)	0.0	1/day
COST	Cost per foot of pervious length	?	$/ft

1. The LENGTH is the decision variable.

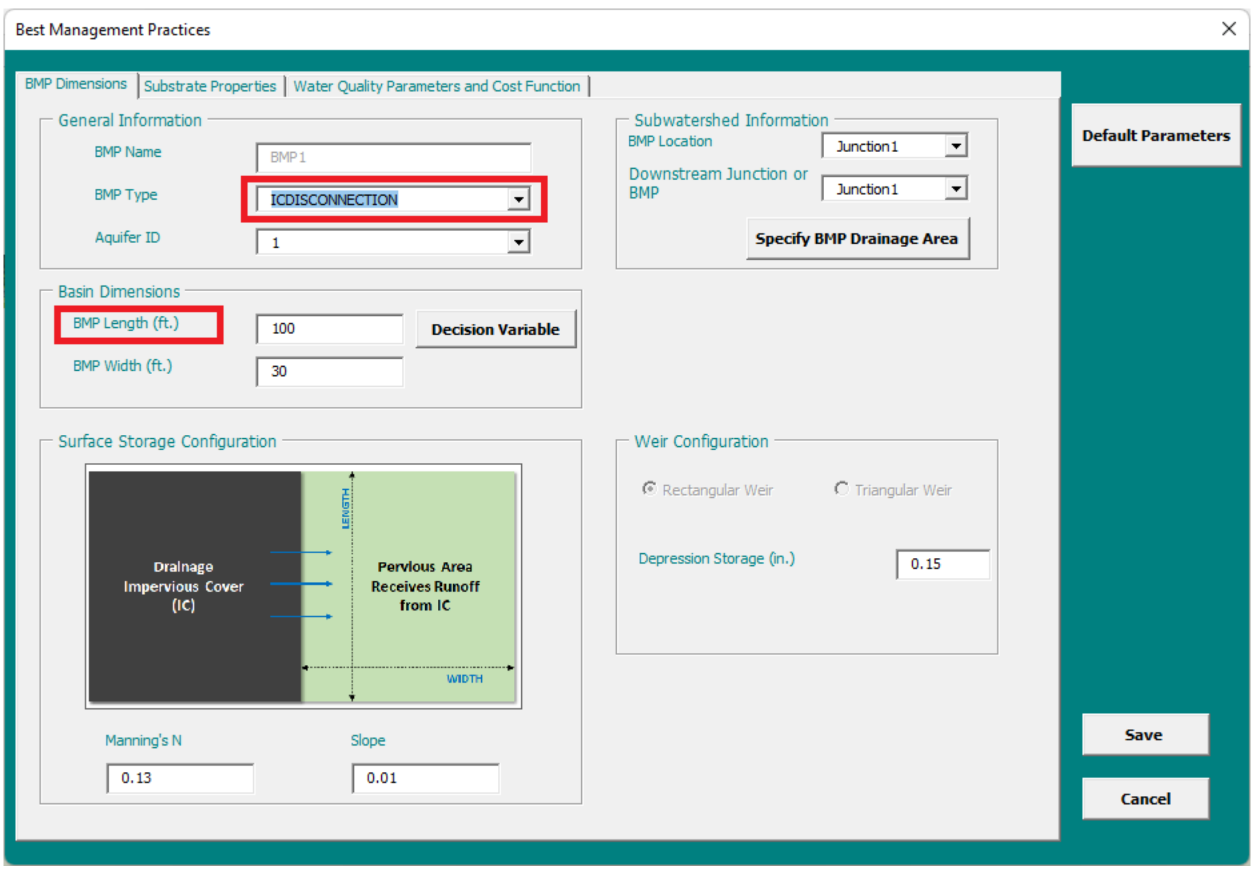

Figure 4-2. IC Disconnection BMP setup window within the Opti-Tool.

5. SUMMARY

Adding the four GI SMCs described in the previous sections provides a powerful new suite of modeling options within the Opti-Tool framework. The IC disconnection with and without storage is particularly attractive from a cost and programmatic standpoint as these types of initiatives require only basic technical knowledge and funding, meaning that homeowners are often able to implement them with little or no expert guidance. The parameters presented in the tables represent basic, midrange default values consistent with the Region 1 climate and landscape. Parameters that are highly site-specific, such as slope and infiltrate rate, can and should be adjusted as necessary for each modeling application. The Opti-Tool does not simulate the rainfall but instead uses the pre-simulated runoff time series as boundary conditions. To simulate the direct rainfall on the BMP footprint, the user has to add the BMP surface area as an impervious HRU area to the BMP drainage area. For example, if 50% of the rooftop area is converted to the *Green Roof* and the remaining 50% of the rooftop area is draining to the *Green Roof* then the drainage area for the *Green Roof* will be 100% of the rooftop area. Similarly, IC disconnection to the pervious area has a significant footprint, so to account for the direct precipitation on the pervious area, an equal amount of impervious HRU area should be added to the drainage area. For example, if 0.5 acres of IC is disconnected and routed to 1.0 acres of pervious area then 1.5 acres of IC should be used as drainage area to the pervious area.

6. REFERENCES

Baryła, A., Karczmarczyk, A., Brandyk, A., & Bus, A. (2018). The influence of a green roof drainage layer on retention capacity and leakage quality. *Water Science and Technology*, 77(12), 2886–2895. https://doi.org/10.2166/wst.2018.283

Marasco, D. E., Hunter, B. N., Culligan, P. J., Gaffin, S. R., & McGillis, W. R. (2014). Quantifying evapotranspiration from urban green roofs: A comparison of chamber measurements with commonly used predictive methods. *Environmental Science and Technology*, 48(17), 10273–10281. https://doi.org/10.1021/es501699h

Razzaghmanesh, M., & Beecham, S. (2014). The hydrological behaviour of extensive and intensive green roofs in a dry climate. *Science of the Total Environment*, 499(1), 284–296. https://doi.org/10.1016/j.scitotenv.2014.08.046

Seters, T. van, Rocha, L., Smith, D., & Macmillan, G. (2009). *Evaluation of Green Roofs for Runoff Retention, Runoff Quality, and Leachability*.

USEPA (United States Environmental Protection Agency). 2012. *Report on Enhanced Framework (SUSTAIN) and Field Applications to Placement of BMPs in Urban Watersheds*. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-11/144, 2012.

USEPA (United States Environmental Protection Agency). 2009. *SUSTAIN – A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality*. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/095, 2009.