Stormwater Modeling Committee
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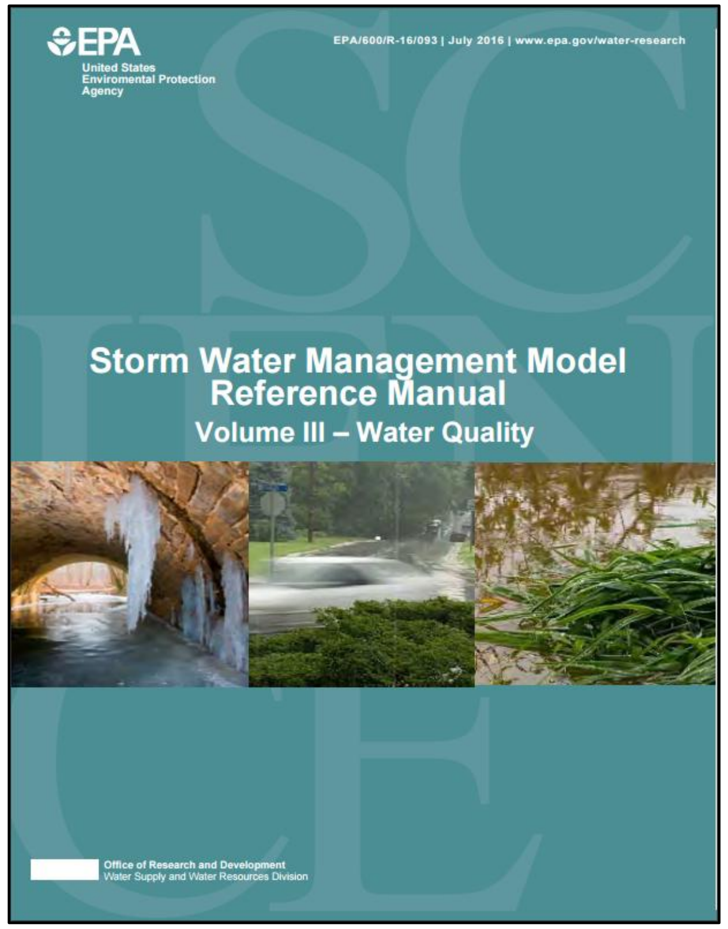
SWMM5 LID Modeling

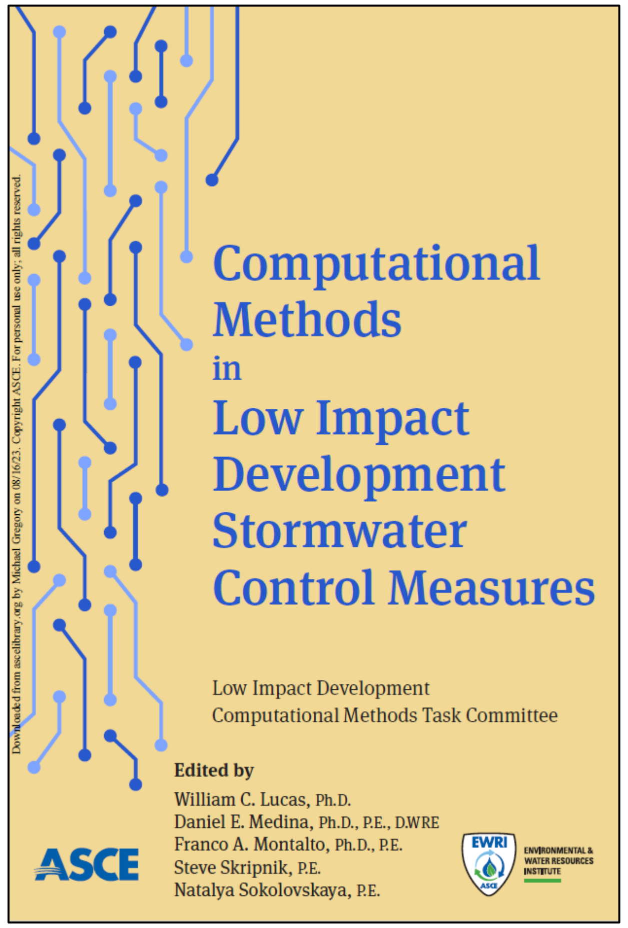
EWRI Congress 2025
EPA SWMM5 Technical Workshop
Anchorage AK, May 18, 2025

Outline

- Green stormwater infrastructure in context
- LID theory in SWMM5
- LID Controls and LID Usage in SWMM5



Reference Manual
Volume III – Water Quality
(see Chapter 6 for lots of LID details and helps)



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EWRI Congress 2025, EPA SWMM5 Workshop -- LID Modeling

Green Infrastructure in Context

LID Defined

Low Impact Development (LID) is a stormwater management strategy that seeks to mitigate the impacts of increased runoff and stormwater pollution by **managing runoff as close to its source as possible**. LID comprises a set of site design strategies that minimize runoff and distributed, small scale structural practices that **mimic natural or pre-development hydrology** through the processes of infiltration, evapotranspiration, harvesting, filtration and retention of stormwater. These practices can effectively remove nutrients, pathogens and metals from runoff, and they reduce the volume and intensity of stormwater flows.

- U.S. Environmental Protection Agency, 2007

General Goals of Stormwater Management

Hazard protection: manage peak flows (during extreme events) to protect people and property from flooding/erosion hazards

Quality treatment: manage sediment, pollution, and temperature to protect public health, habitats, and aquatic/terrestrial resources

Volume control: manage stormwater in a way that mimics pre-development conditions to preserve the natural hydrology

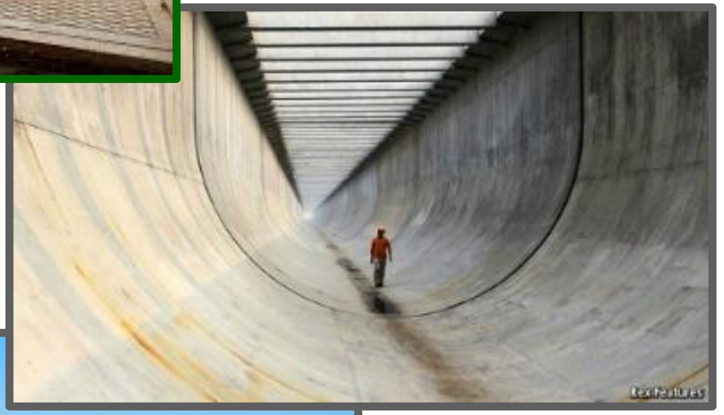
Flow maintenance: manage the intensity, duration, and frequency of environmental flows (over a wide operating range) to preserve receiving waters and protect sensitive ecosystems

LEGEND

	Grey infrastructure
	Green infrastructure
	Grey + Green

Dealing with Development – Four Options

- Source controls: Capture and use runoff before it gets into the collection system
- Conveyance improvements: Move runoff quickly and efficiently through the collection system
- Storage improvements: Hold runoff within the collection system before discharging it downstream
- Floodplain management: Redirect/contain damaging flows OR get out of its way



LEGEND

Green Infrastructure

Grey Infrastructure

Detention versus Retention

- Detention (rate control):
  - Facilities designed to temporarily detain the water
  - Function is to dispose of runoff at a desired rate
  - Provides peak flow/velocity attenuation
  - Volume OUT = Volume IN
- Retention (volume control):
  - Facilities designed to permanently retain the water
  - Function is to keep the runoff at its source
  - Provides volume reduction
  - Volume OUT < Volume IN

On-Site Retention

- Hydrologic Water Balance: Capture and retain rainfall/snowmelt in a manner that preserves the native hydrology through natural or engineered features
- Consumptive/Beneficial Use: Capture and retain rainfall for non-potable water demands that were previously serviced via municipal water supply (reuse)
  - Landscape irrigation
  - Toilet/urinal flushing
  - Ornamental fountains
  - Vehicle and equipment washing
  - Dust control
  - Cooling/process water, ice/snowmaking, auxiliary source for firefighting

On-Site Retention Benefits

- Primary benefits are volume control and environmental flow maintenance
- Flood control: attenuation can reduce peak flow rates
- Erosion control: attenuation can reduce depths, velocities, shear stresses, etc.
- Water quality treatment: less runoff = less pollutant loading to receiving waters
- Developers
  - Reduced facility sizes (smaller pipes & ponds)
  - Environmental appeal (LEED credits = higher sale price)
- Property owners
  - Claim stormwater utility credits
  - Save potable water costs
  - Showcase environmental friendliness

On-Site Retention Examples

- Evapotranspiration
  - Evaporation from surface storage
  - Transpiration/evaporation by vegetation
- Surface runoff
  - Disconnect impervious areas
- Reuse
  - Rainwater harvesting system
- Infiltration
  - Basin/trench (at grade)
  - Gallery (below grade)





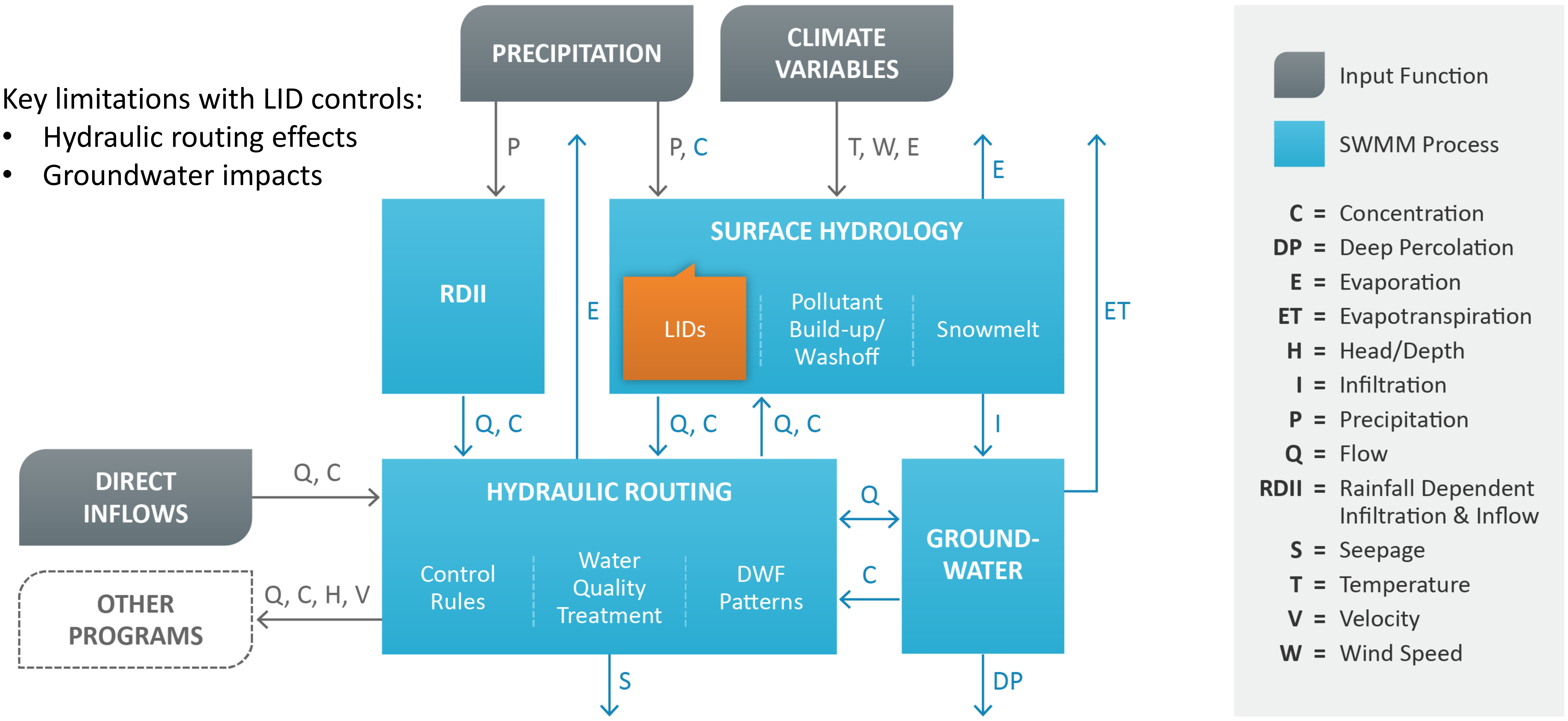


LID Theory in SWMM5

SWMM Process Schematic

Key limitations with LID controls:

- Hydraulic routing effects
- Groundwater impacts



LID Assumptions

1. The LID footprint of the unit remains constant throughout its depth
2. Flow through the unit is one-dimensional in the vertical direction
3. Inflow to the unit is distributed uniformly over the top surface
4. Moisture content is uniformly distributed throughout the soil layer
5. Matric forces within the storage layer are negligible so that it acts as a simple reservoir that stores water from the bottom up
6. The water depth is uniform across the surface and storage layers

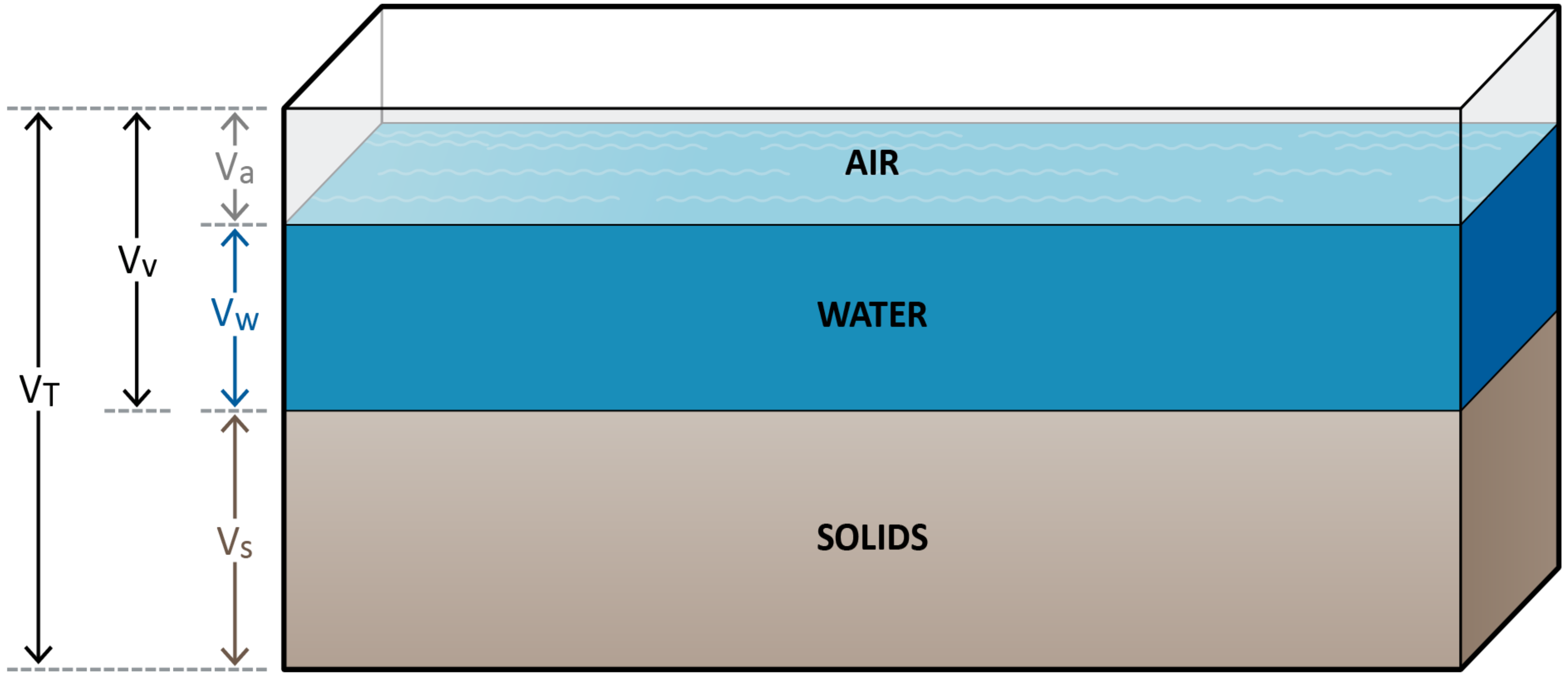
Definitions

- Volumetric water content: $\theta = \dfrac{V_w}{V_T}$
- Porosity (void fraction of bulk volume):

$$\varphi = \frac{V_w + V_a}{V_T} \qquad \varphi = \frac{e}{1+e}$$

- Void ratio (voids versus volume of solids):

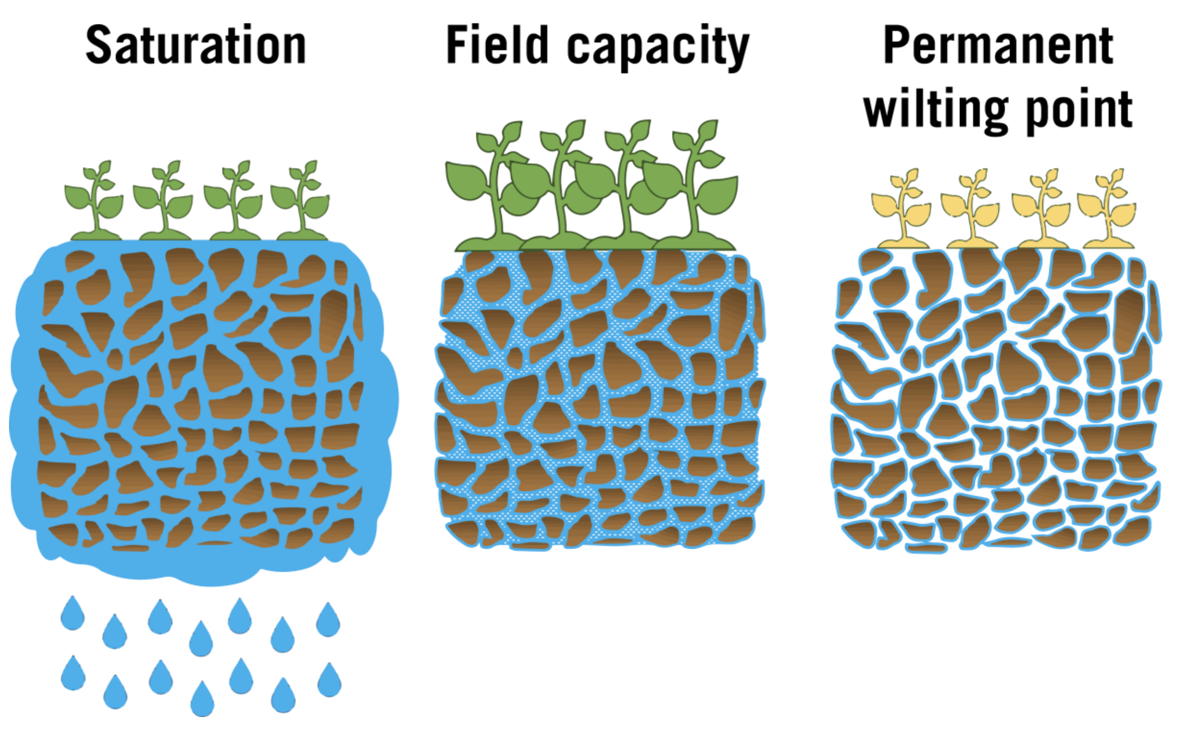
$$e = \frac{V_w + V_a}{V_s} \qquad e = \frac{\varphi}{1-\varphi}$$

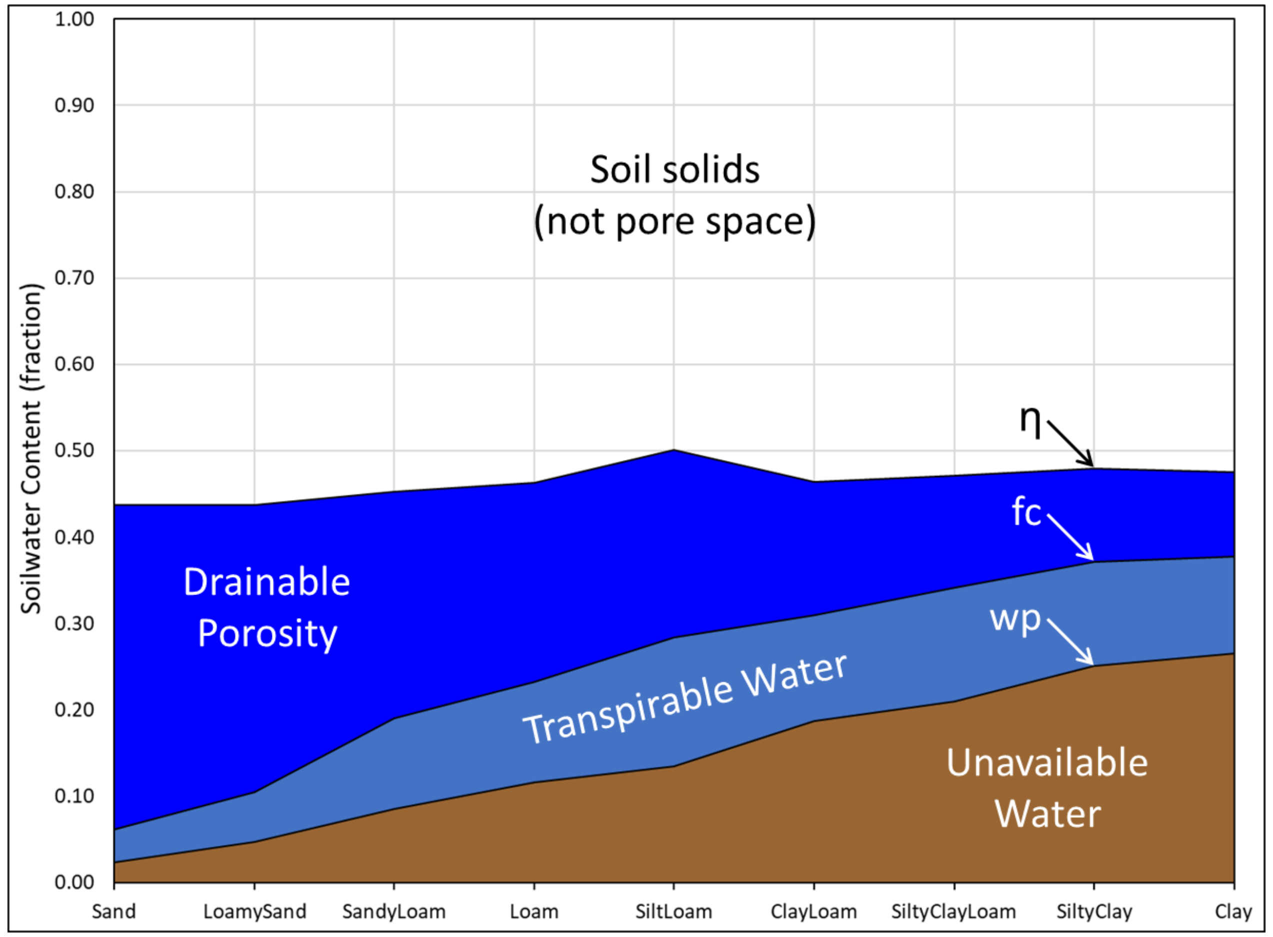


V_T = Total bulk volume

Definitions

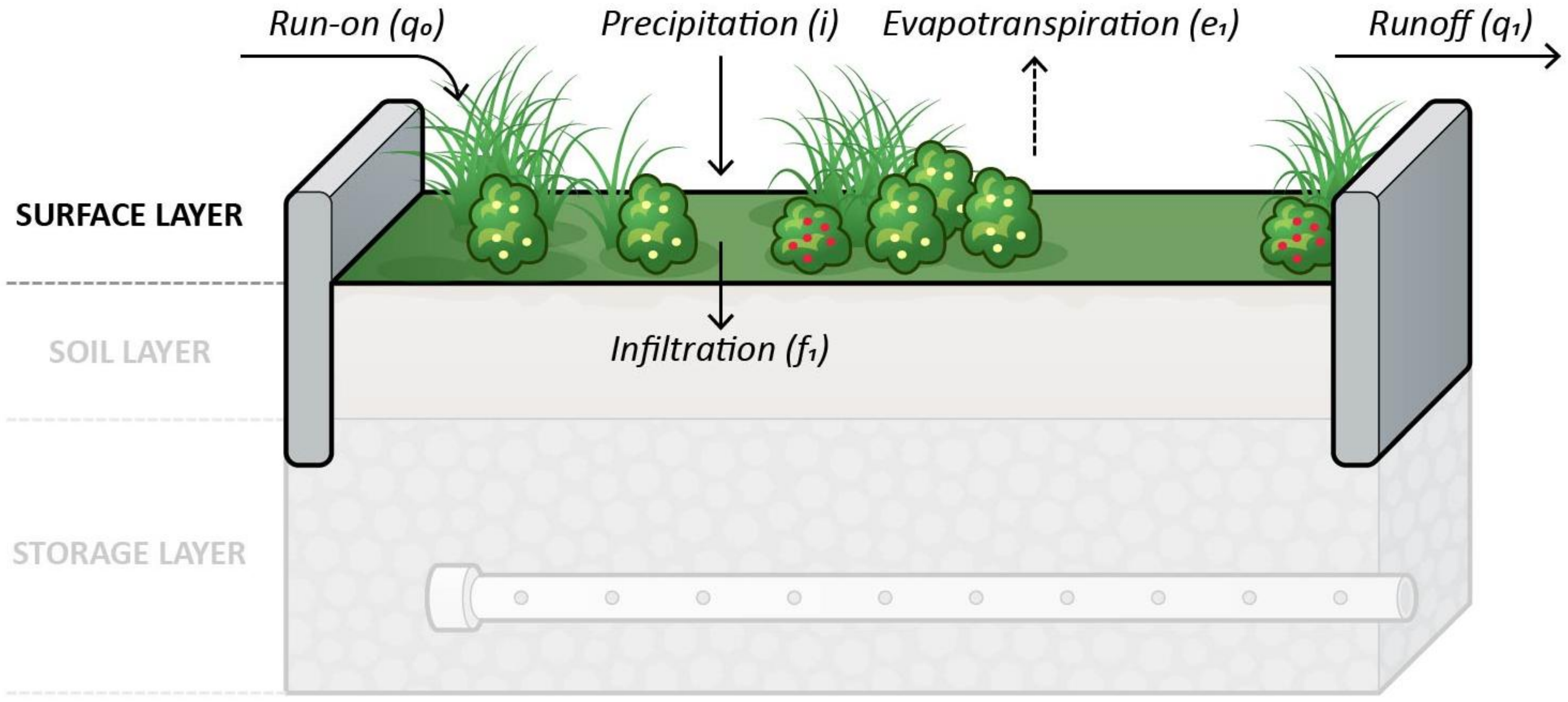
- Porosity (η) is a measure of the pore space that can hold a mixture of water and air
- Wilting point (wp): plants cannot extract water from the soil when soilwater content (θ) is below wp
- Field capacity (fc): water is held against gravity
- Degree of saturation is often referenced between the wilting point and porosity
    - At 0% saturation, θ = wp
    - At 100% saturation, pore space is full of water (θ = η)
    - At field capacity, θ is somewhere in between wp and η





Surface/Ponding Layer

$$\varphi_1 \frac{\partial d_1}{\partial t} = i + q_0 - e_1 - f_1 - q_1$$



φ_1 = surface layer porosity (volume not filled with vegetation)

d_1 = surface layer water depth

i = direct rainfall on surface layer

q_0 = inflow to surface layer (run-on)

e_1 = surface layer evapotranspiration rate

f_1 = infiltration rate of surface water

q_1 = surface layer runoff rate (overflow)

Surface Runoff

$$q_1 = \frac{1.49}{n_1}\sqrt{S_1}\left(\frac{W_1}{A_1}\right)\varphi_1(d_1 - D_1)^{5/3}$$

q_1 = surface layer runoff rate (overflow)

n_1 = surface roughness (Manning's coefficient)

S_1 = surface slope

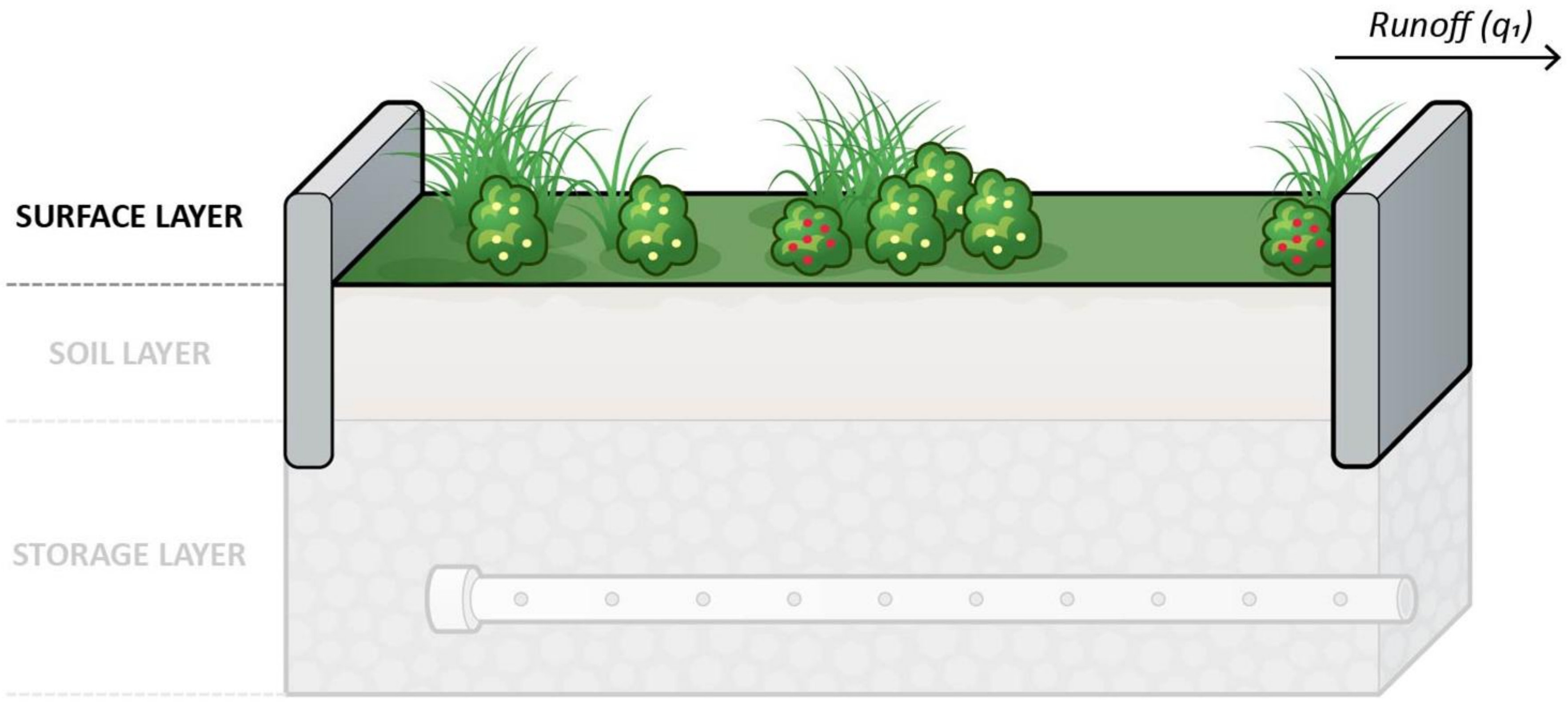
A_1 = surface area

φ_1 = surface layer porosity (volume not filled with vegetation)

d_1 = surface layer water depth

D_1 = berm height/depression storage depth

W_1 = surface width of LID



Infiltration

$$f_1 = K_{2S}\left(1 + \frac{(\varphi_2 - \theta_{20})(d_1 + \omega_2)}{F}\right)$$

f_1 = infiltration rate of surface water

K_{2S} = soil's saturated hydraulic conductivity

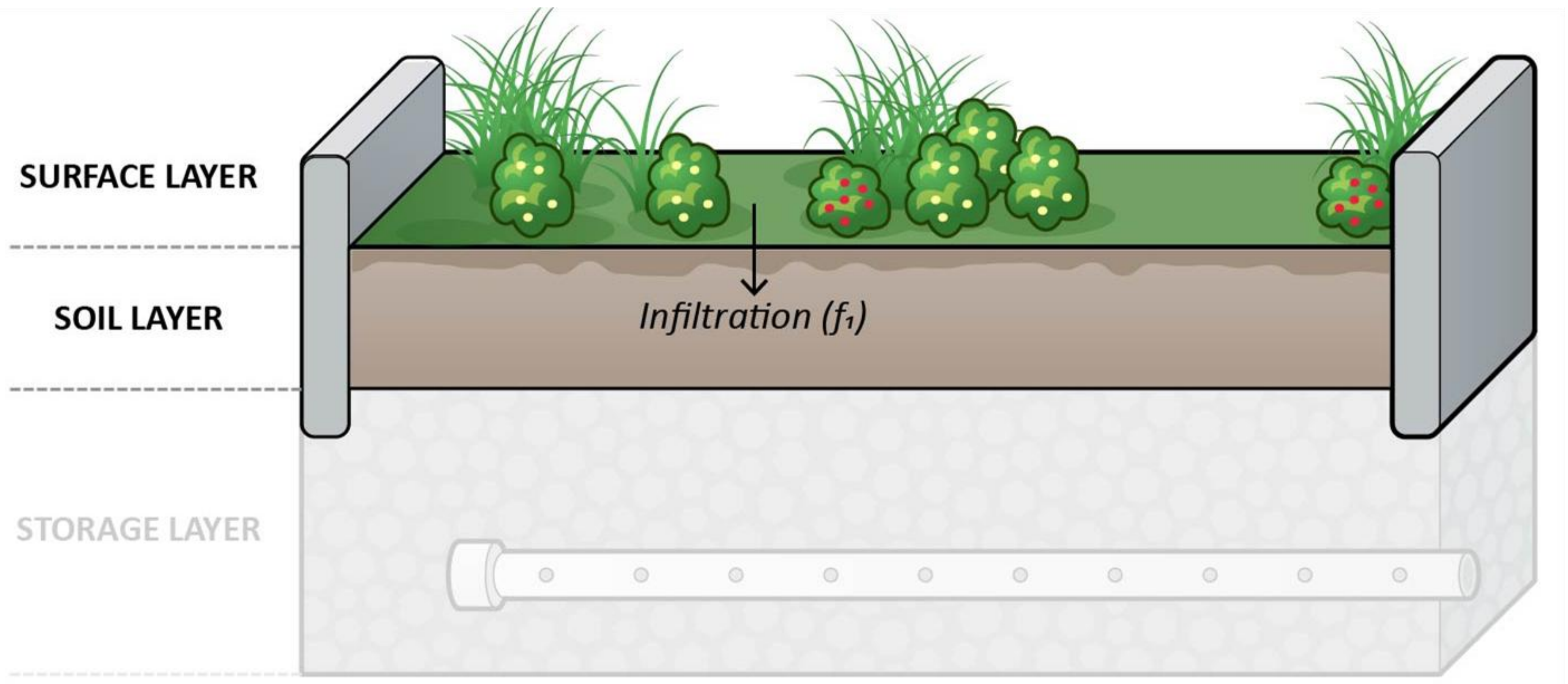
φ_2 = soil layer porosity

θ_{20} = moisture content at the top of the soil layer

d_1 = surface layer water depth

ω_2 = suction head at the infiltration wetting front formed in the soil

F = cumulative infiltration volume per unit area over a storm event

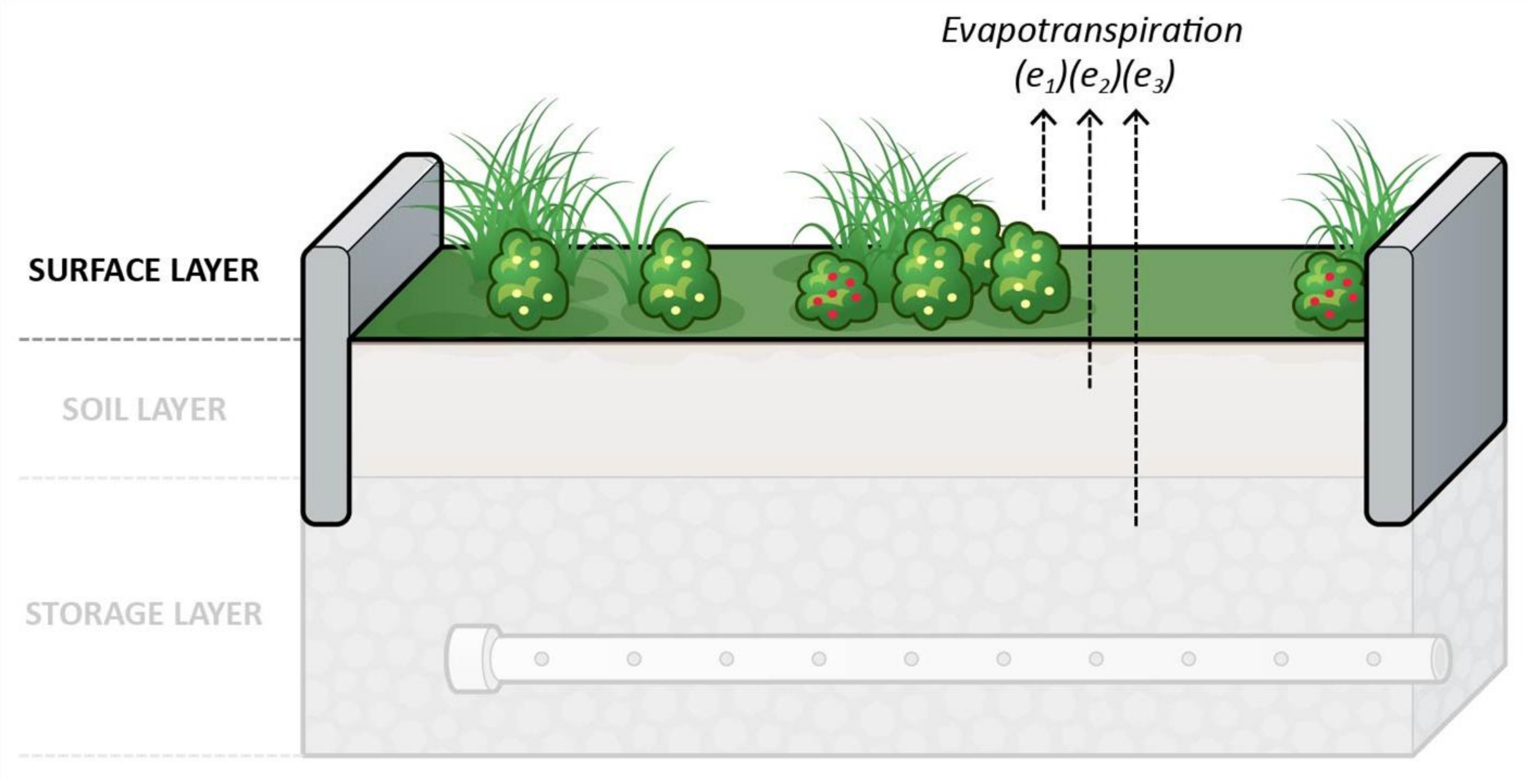


Evapotranspiration (ET)

$$e_1 = min[E_0(t), d_1/\Delta t]$$

$$e_2 = min[E_0(t) - e_1, (\theta_2 - \theta_{WP})D_2/\Delta t]$$

$$e_3 = \begin{cases} min[E_0(t) - e_1 - e_2, \varphi_3 d_3/\Delta t\ ], \theta_2 < \varphi_2 \\ 0, \theta_2 \geq \varphi_2 \end{cases}$$



e_1	= surface layer ET rate
e_2	= soil layer ET rate
e_3	= storage layer ET rate
$E_0(t)$	= potential ET rate that applies for time t
φ_2	= soil layer porosity
φ_3	= void fraction of the storage layer
θ_2	= soil layer water content
θ_{WP}	= water content at wilting point
d_1	= surface layer water depth
d_3	= storage layer water depth
D_2	= soil layer thickness
Δt	= time step

Soil Layer

$$D_2 \frac{\partial \theta_2}{\partial t} = f_1 - e_2 - f_2$$

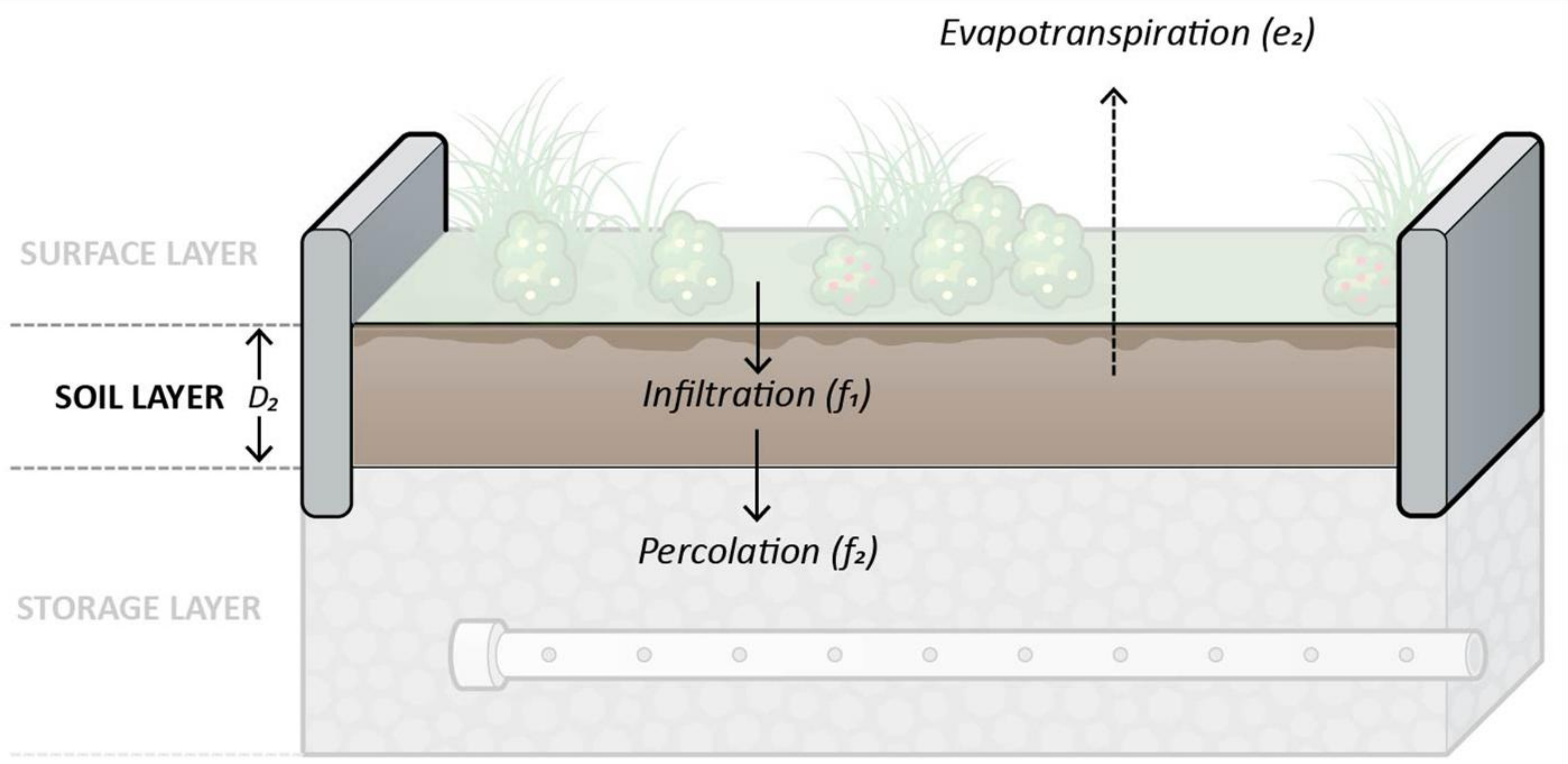
D_2 = soil layer thickness

θ_2 = soil layer water content

f_1 = infiltration rate of surface water

e_2 = soil layer evapotranspiration rate

f_2 = percolation rate of soil layer water



Percolation

$$f_2 = \begin{cases} K_{2S}\, exp[-HCO(\varphi_2 - \theta_2)], \theta_2 > \theta_{FC} \\ 0, \theta_2 \leq \theta_{FC} \end{cases}$$

f_2 = percolation rate of soil layer water

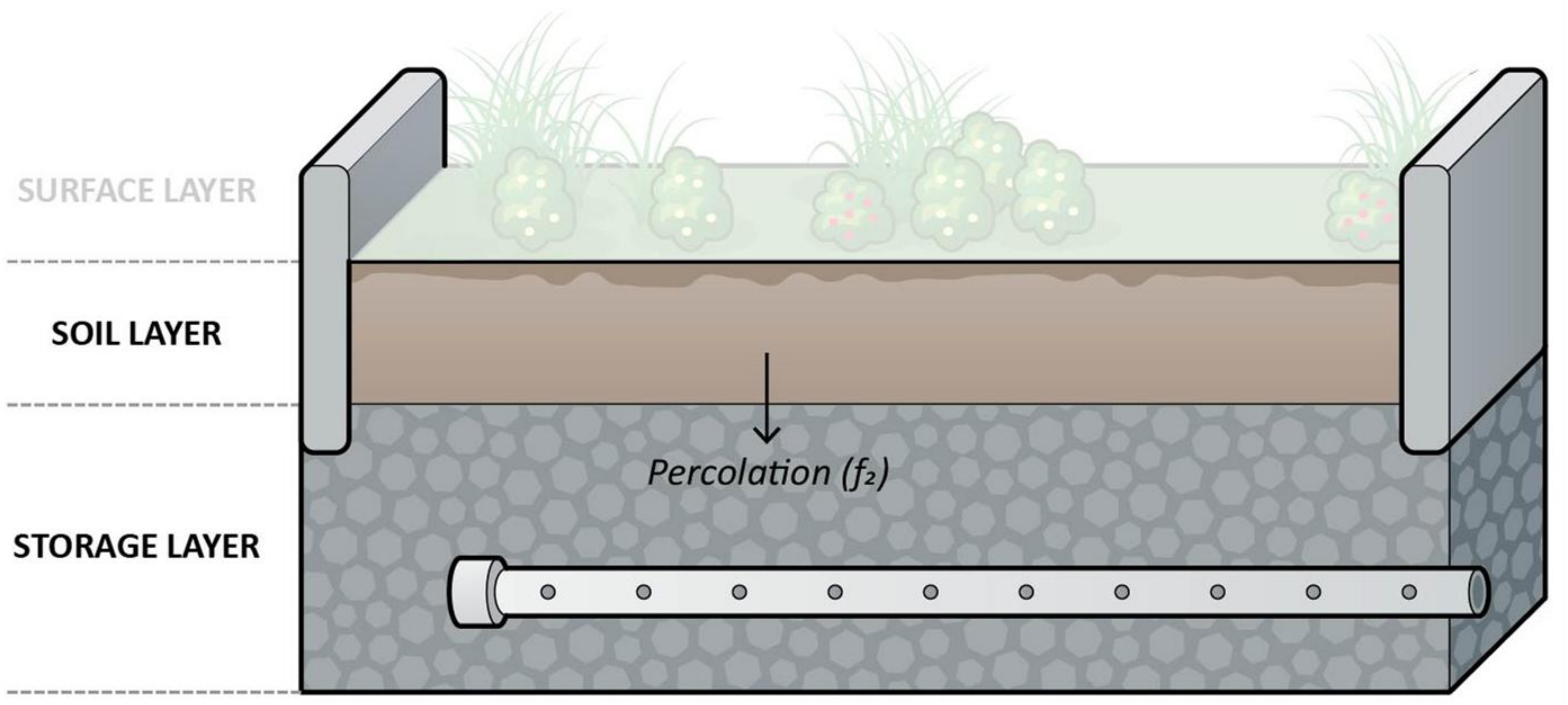
K_{2S} = soil's saturated hydraulic conductivity

HCO = decay constant

φ_2 = soil layer porosity

θ_2 = soil layer water content

θ_{FC} = water content at field capacity



Pavement Layer

$$D_4(1-F_4)\frac{\partial\theta_4}{\partial t} = f_1 - e_4 - f_4$$

D_4 = pavement layer thickness

F_4 = impermeable paver block fraction

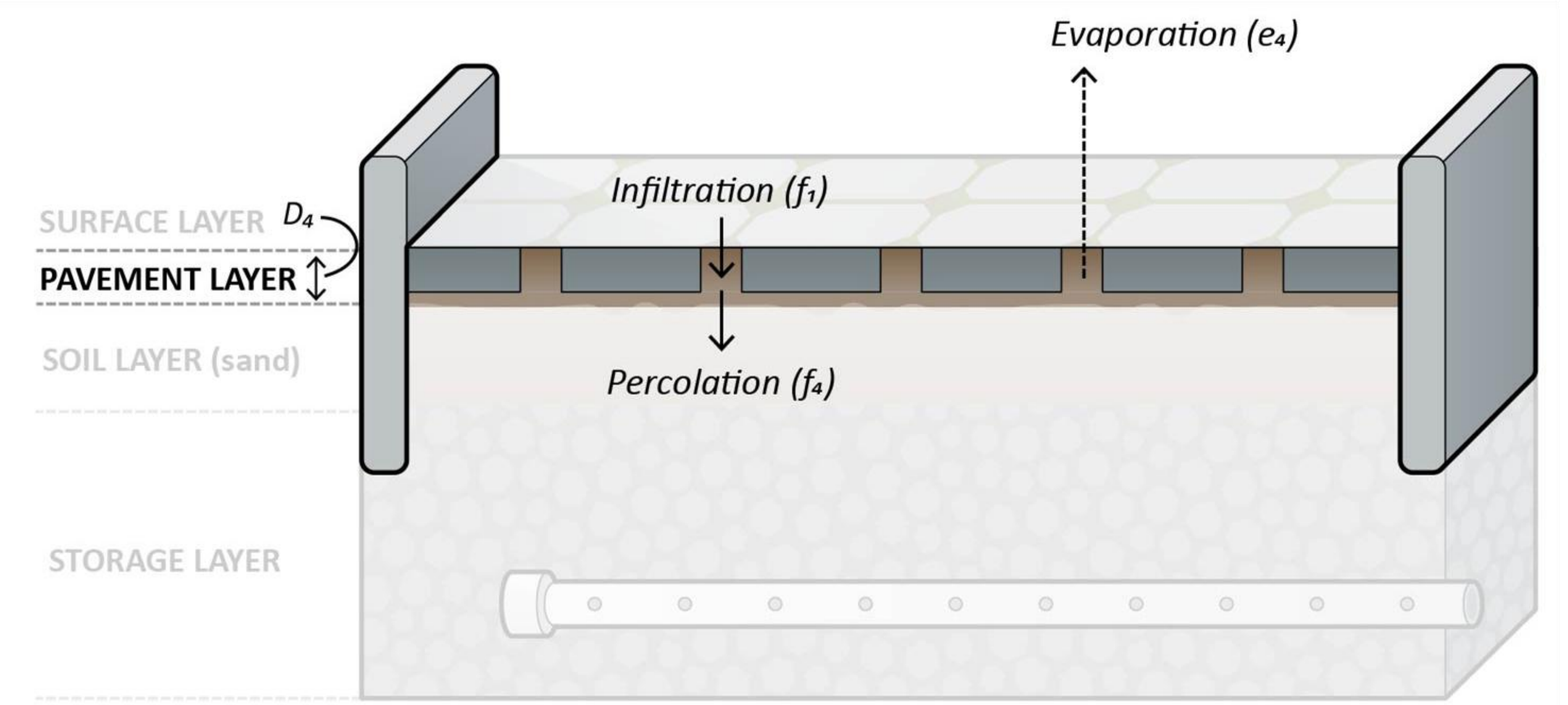
($1 - F_4$ is the surface opening fraction)

θ_4 = pavement layer water content

f_1 = infiltration rate of surface water

e_4 = pavement layer evaporation rate

f_4 = percolation rate of pavement layer water



$$f_1 = i + q_o + d_1/\Delta t$$

i = direct rainfall on surface layer

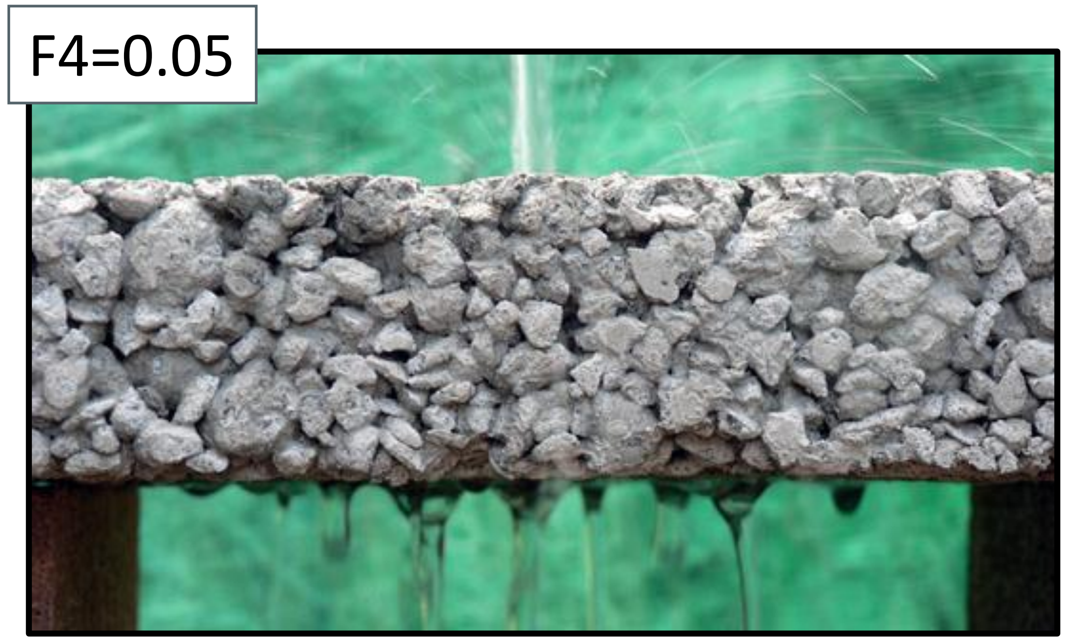
q_o = inflow to surface layer (run-on)

d_1 = surface layer water depth

Δt = time step

Permeable Pavement

- A continuous porous system is an excavated area filled with gravel and paved over with a porous concrete or asphalt mix
- A block paver system consists of impervious paver blocks placed on sand or pea gravel with a storage layer below
- Important parameter, F_4: Fraction of LID surface area covered by impermeable material



Storage Layer

$$\varphi_3 \frac{\partial d_3}{\partial t} = f_2 - e_3 - f_3 - q_3$$

φ_3 = storage layer porosity

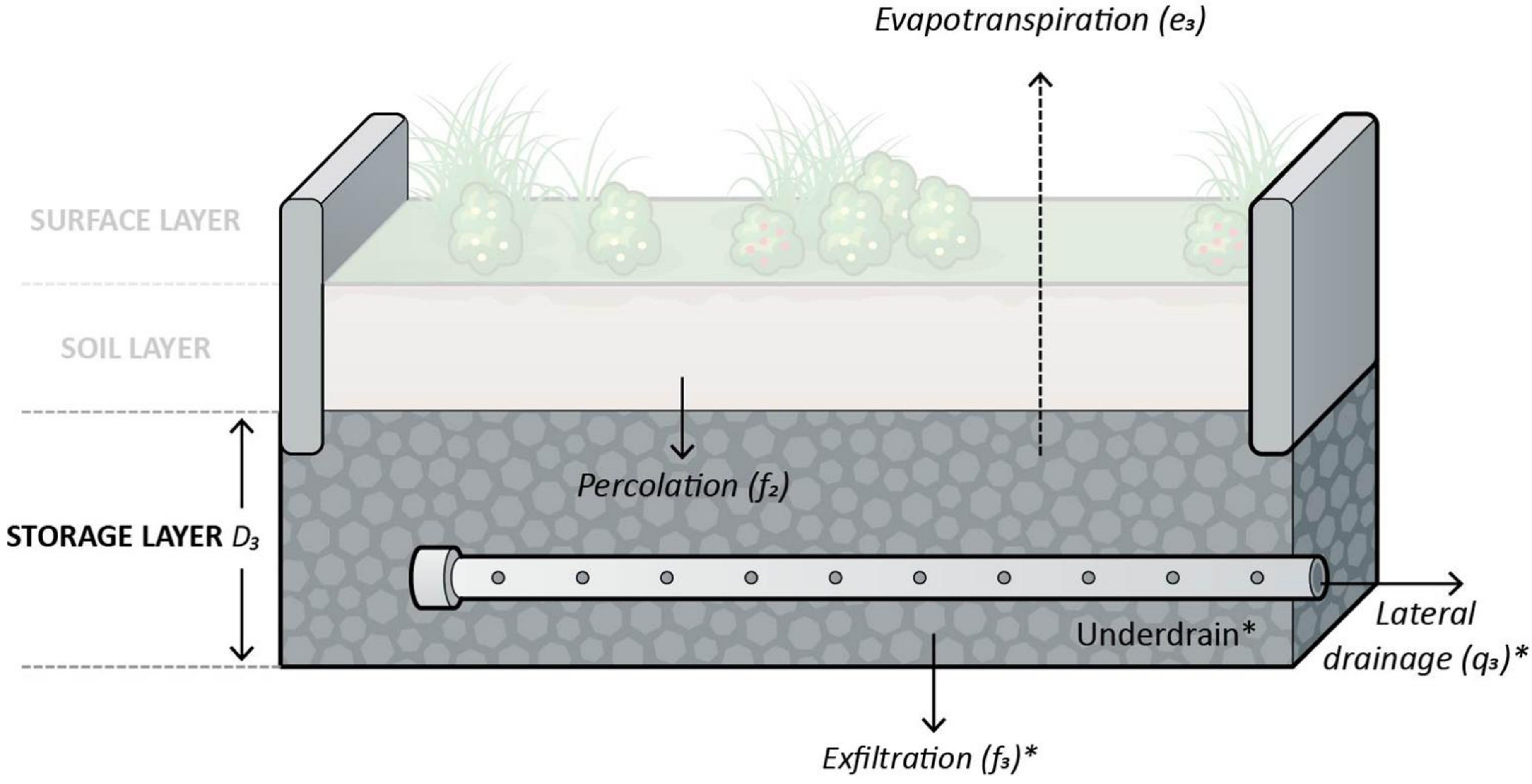
d_3 = storage layer water depth

f_2 = percolation rate of soil layer water

e_3 = storage layer evapotranspiration rate

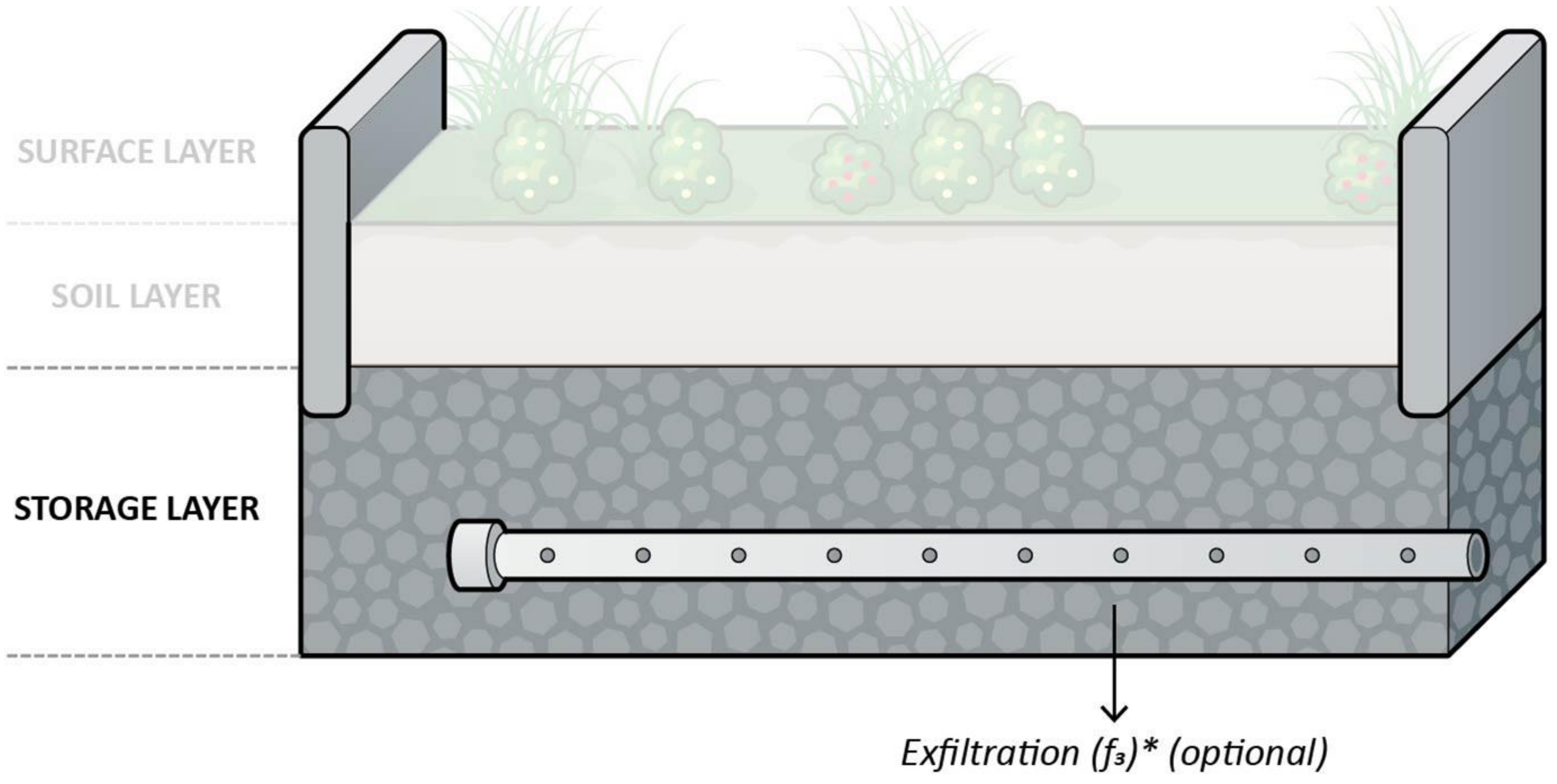
f_3 = exfiltration rate of storage layer water

q_3 = storage layer underdrain outflow rate



Exfiltration

- SWMM5 assumes that the exfiltration rate of the storage layer, f_3, is the user-supplied saturated hydraulic conductivity of the native soil beneath the LID
- This is the term used in EPA SWMM, others may refer to this as recharge, deep infiltration, percolation, seepage, etc.

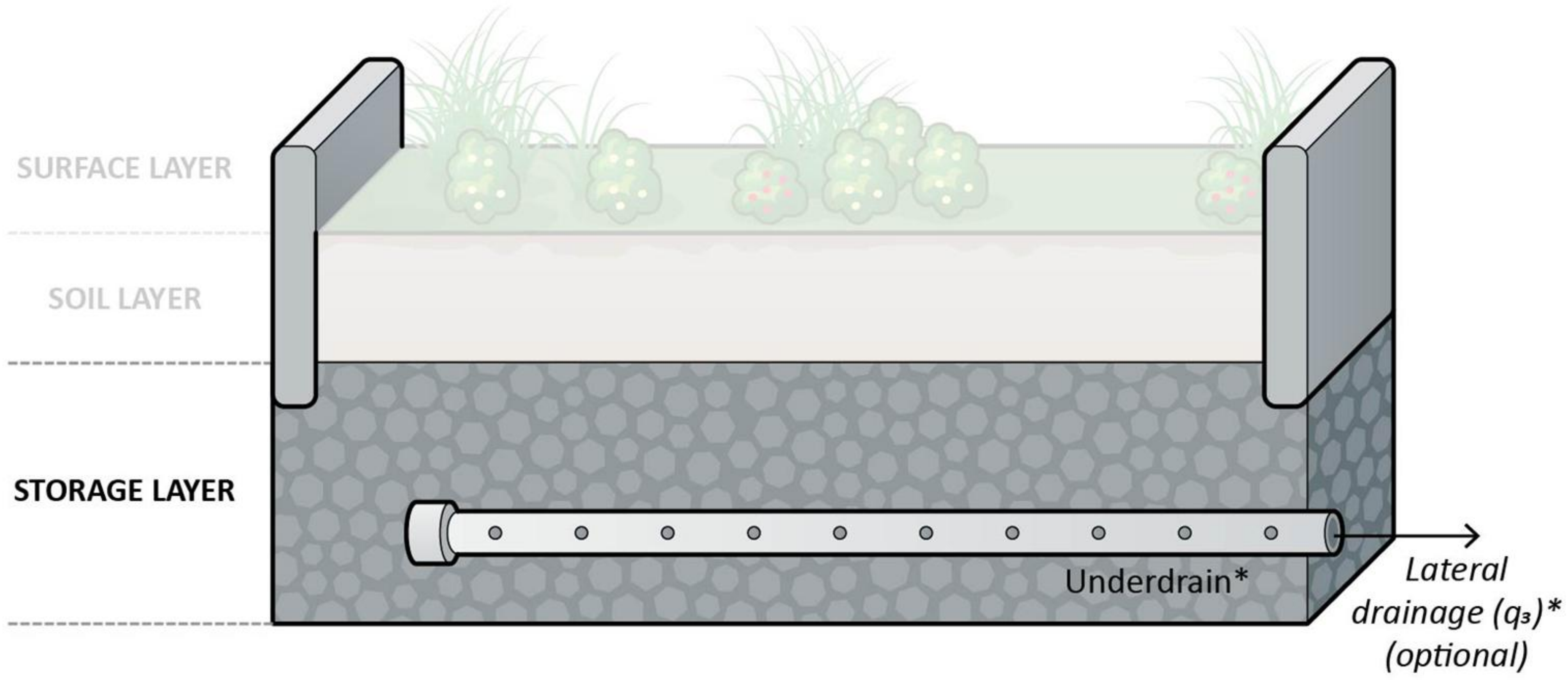


Underdrain

$$q_3 = C_{3D}(h_3)^{\eta_{3D}}$$

Where:

q_3 = underdrain outflow
h_3 = hydraulic head seen by underdrain
C_{3D} = underdrain discharge coefficient
η_{3D} = underdrain discharge exponent



Drain Coefficient Equation

Manning's Equation (US units)

$$Q_{full} = (0.464/n_{pipe}) S_{pipe}{}^{0.5} D_{pipe}{}^{2.67}$$

$$C_{3D} = N_{pipe} Q_{full} / A_{LID}$$

Where:

n_{3D}	= 0 (discharge exponent)
Q_{full}	= flow rate of full pipe
n_{pipe}	= roughness coefficient of pipe
S_{pipe}	= slope of pipe
D_{pipe}	= pipe diameter
C_{3D}	= drain coefficient
N_{pipe}	= number of drain pipes in LID

LID Underdrain as an Orifice (US units)

$$Q = C_d A_{orif} \sqrt{\frac{g}{6}} = C_{3D} \frac{A_{LID}}{43200}$$

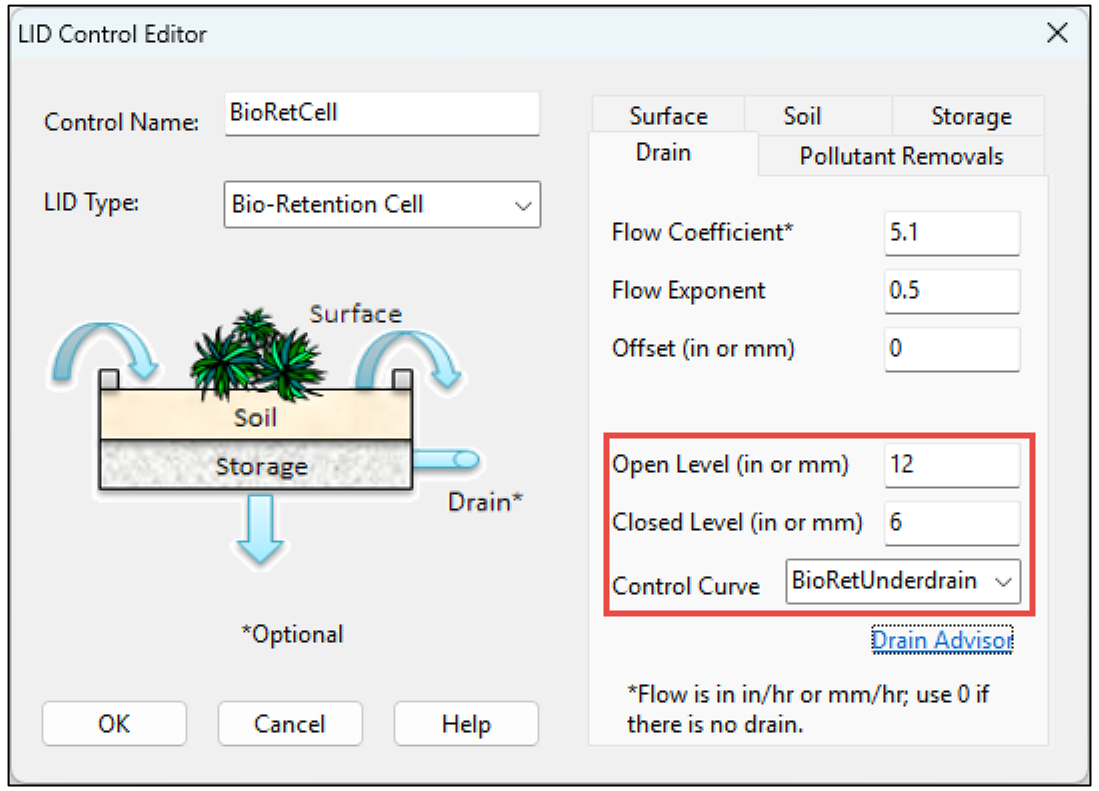
$$C_{3D} = 43200 \sqrt{\frac{g}{6}} C_d \frac{A_{orif}}{A_{LID}}$$

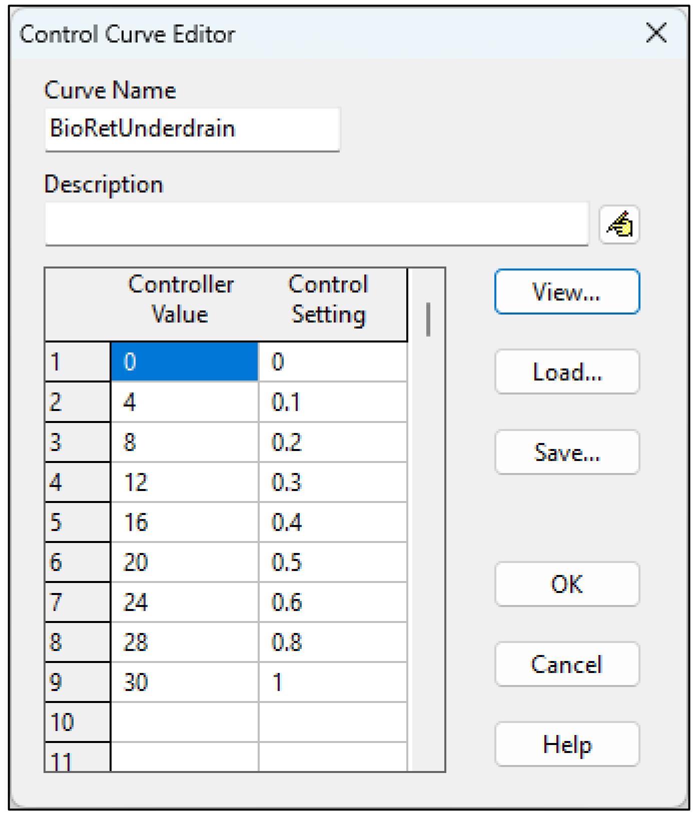
Where:

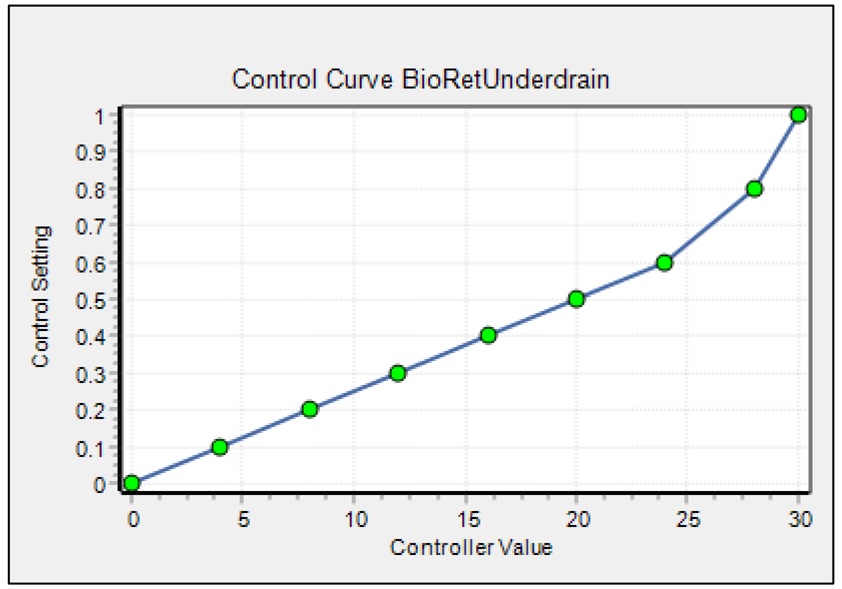
n_{3D}	= 0.5
Q	= flow (cfs, assuming $Q_{orif} = Q_{LID}$)
A_{orif}	= cross-sectional flow area (ft^2)
A_{LID}	= footprint area of all replicate LID units (ft^2)
C_d	= orifice coefficient of discharge, typically in the range of 0.6-0.65
g	= gravitational constant (32.17 ft/s^2)

Underdrain Control (optional)

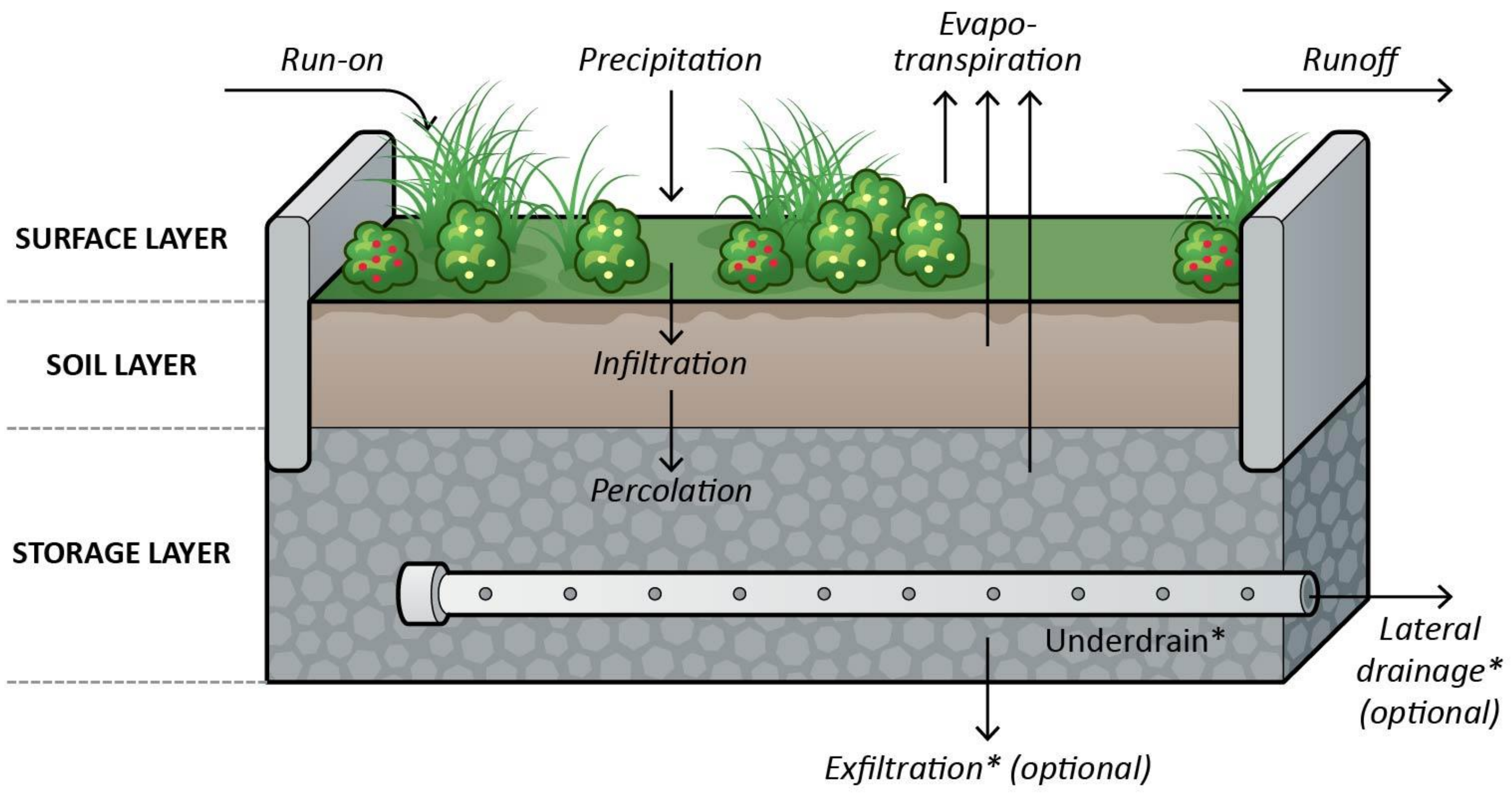
- Open Level: Water depth above which a closed underdrain automatically opens
- Closed Level: Water depth below which an underdrain automatically closes
- Control Curve: Specifies how the nominal drain flow rate is adjusted as a function of the head on the drain (i.e., outflow vs depth rating curve)







Pollutant Removal



- Percent removal for each pollutant can be specified for the flow leaving the LID through the underdrain

LID Control Type	Pollutant Removal
Rain barrel	✓
Vegetative swale	X
Infiltration trench	✓
Rain garden	X
Bio-retention cell	✓
Green roof	X
Permeable pavement	✓
Rooftop disconnection	X

Clogging Factor

If one has an estimate of the number of years it takes to fully clog the system (T_{clog}), the Clogging Factor can be computed as:

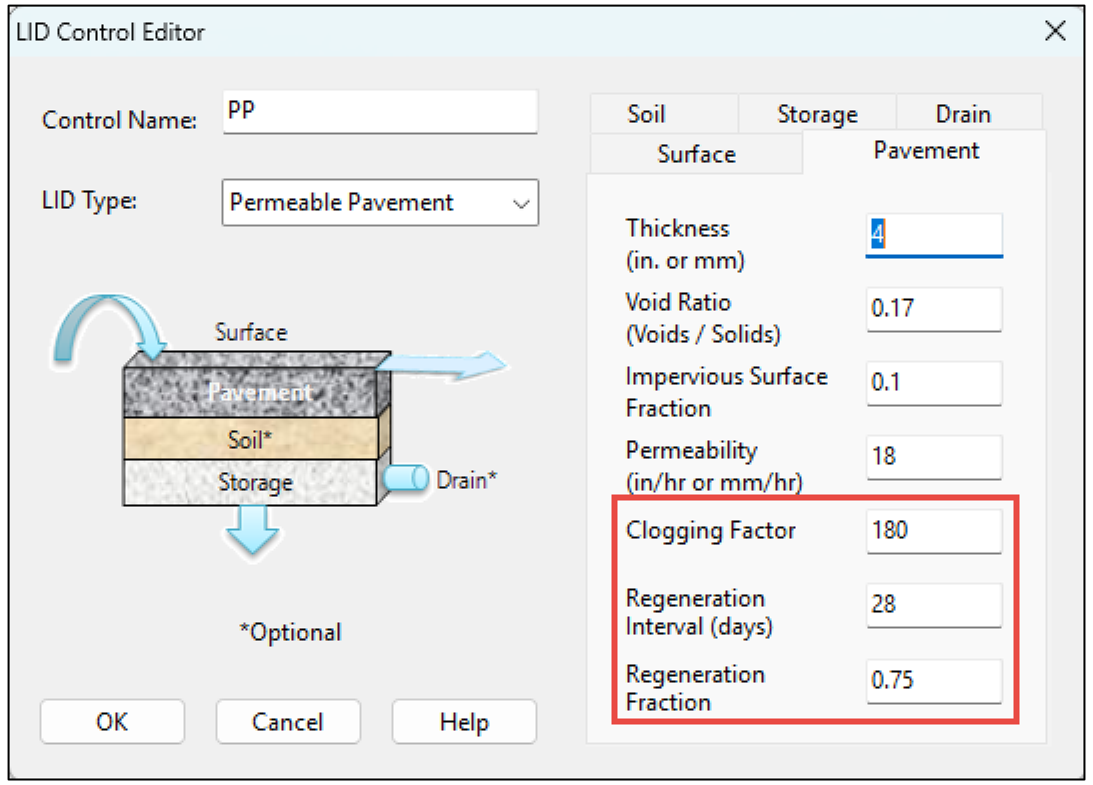
$$\text{CF} = \frac{I_a(1 + R_{LID})T_{clog}}{\varphi D(1 - F_4)F_{clog}}$$

Where:

- T_{clog} = Number of years to reduce the infiltration rate to a degree of F_{clog}
- I_a = Annual volume of rainfall
- R_{LID} = Unit's capture ratio equal to: $R_{LID} = \frac{\text{Contributing runoff area}}{\text{Area of pavement}}$
- φ = Porosity of the pavement layer
- F_4 = Fraction of LID footprint covered by impermeable material
- D = Thickness of the pavement
- F_{clog} = The degree of clogging (fraction)

Recovery of Clogging

- Regeneration Interval: Number of days that the pavement layer is allowed to clog before its permeability is restored (i.e., by vacuuming)
- Regeneration Fraction: Degree to which the pavement's permeability is restored when a regeneration interval is reached (0 = no restoration, 1 = full restoration to original permeability)
- Once a regeneration occurs, clogging of the pavement layer can begin again



LID Control Layer	Clogging	Recovery of Clogging
Surface	X	X
Pavement	✓	✓
Soil	X	X
Storage	✓	X
Underdrain	X	X
Drainage Mat	X	X
Underdrain	X	X

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LID Controls and LID Usage in SWMM5

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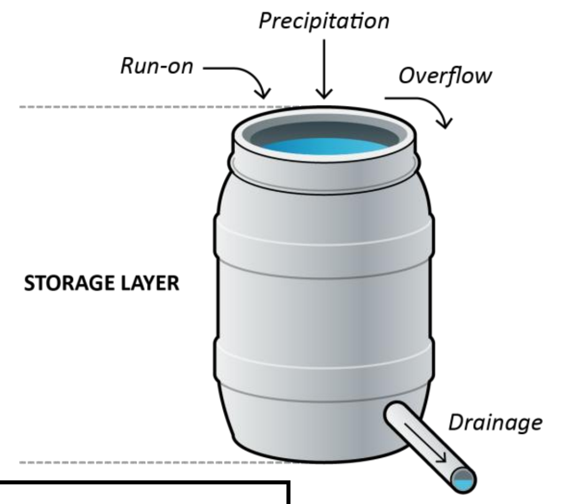
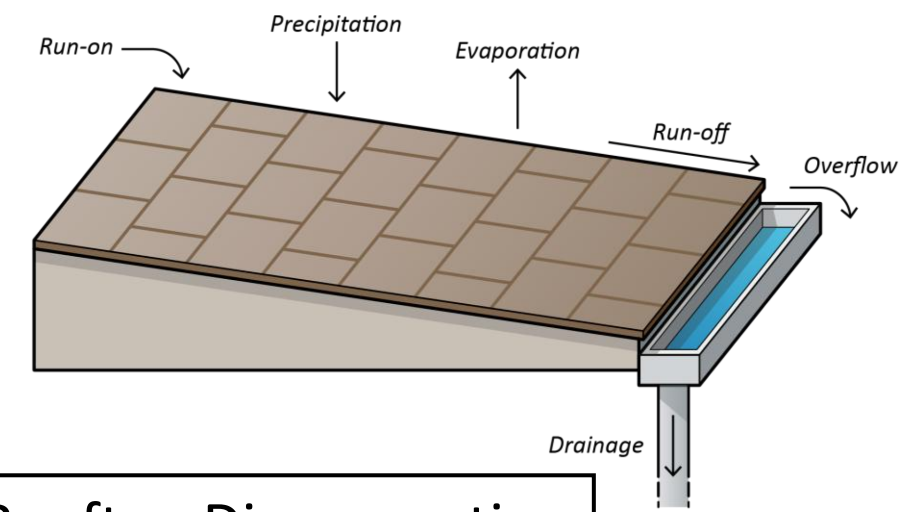
LID Facility Types

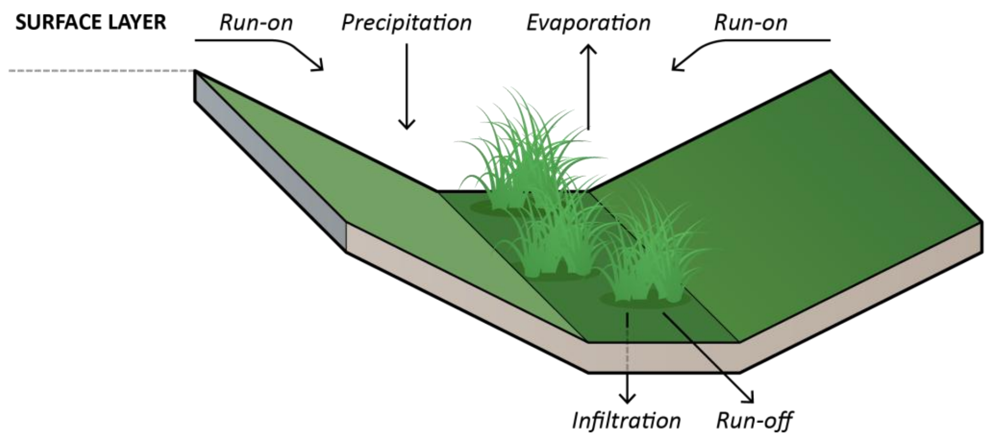
- Eight pre-defined LID “controls” are available in SWMM5



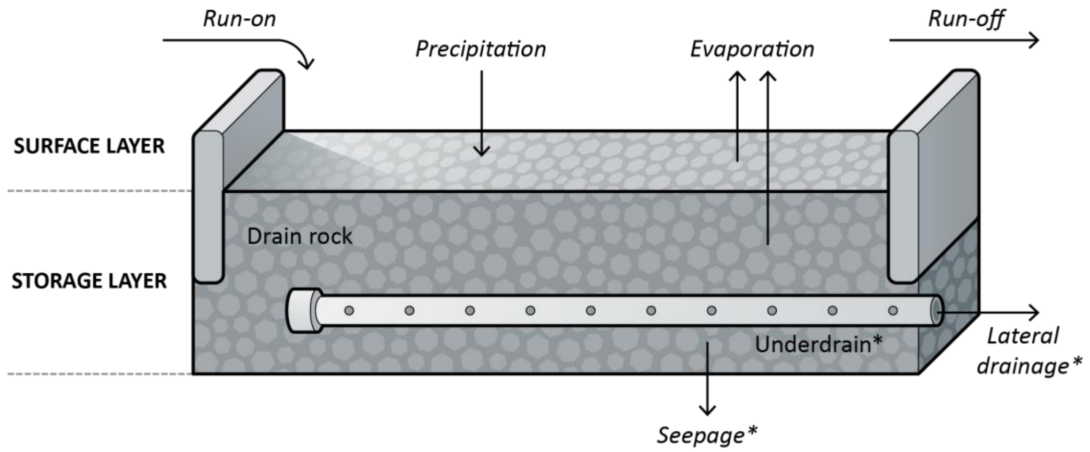
Rain Barrel



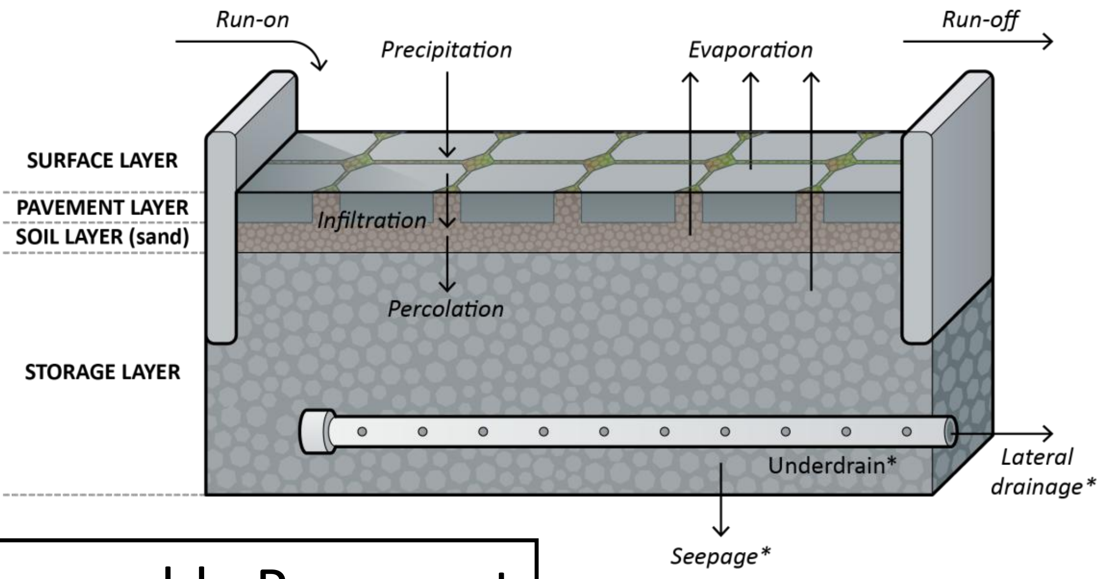
Rooftop Disconnection



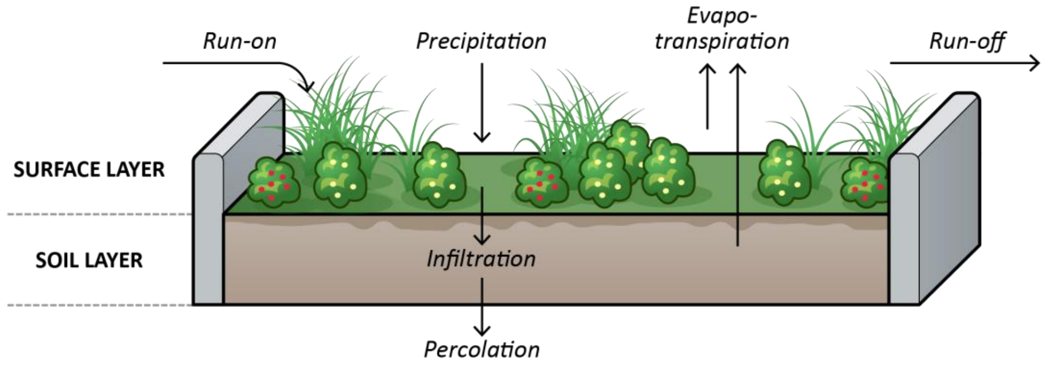
Vegetative Swale



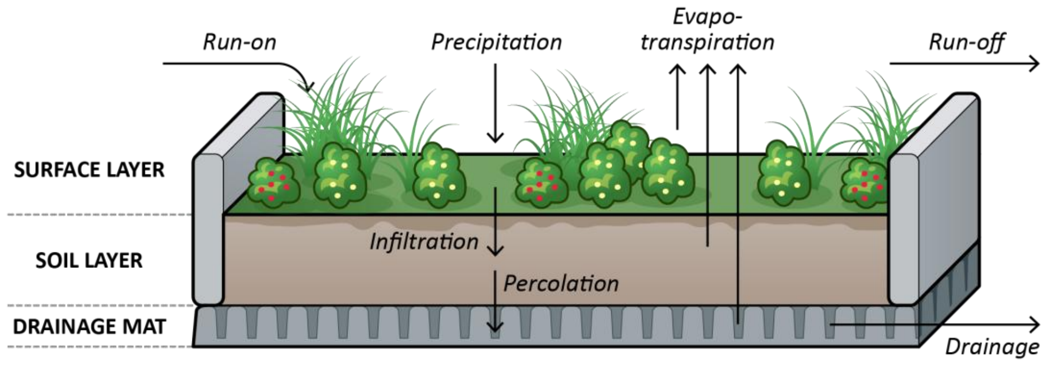
Infiltration Trench



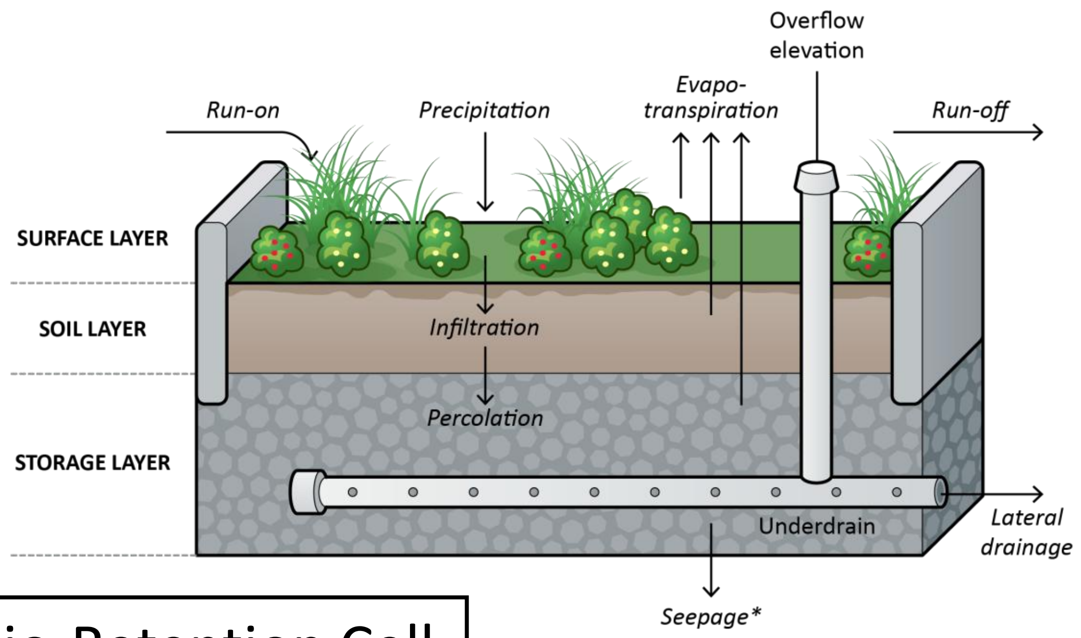
Permeable Pavement



Rain Garden

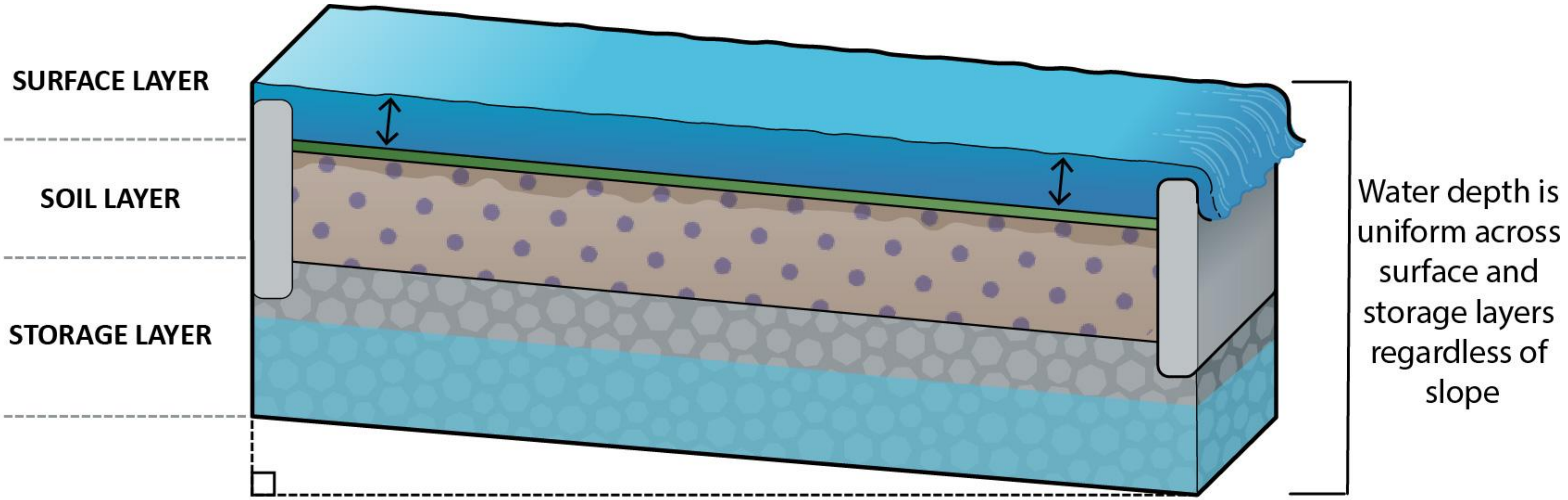


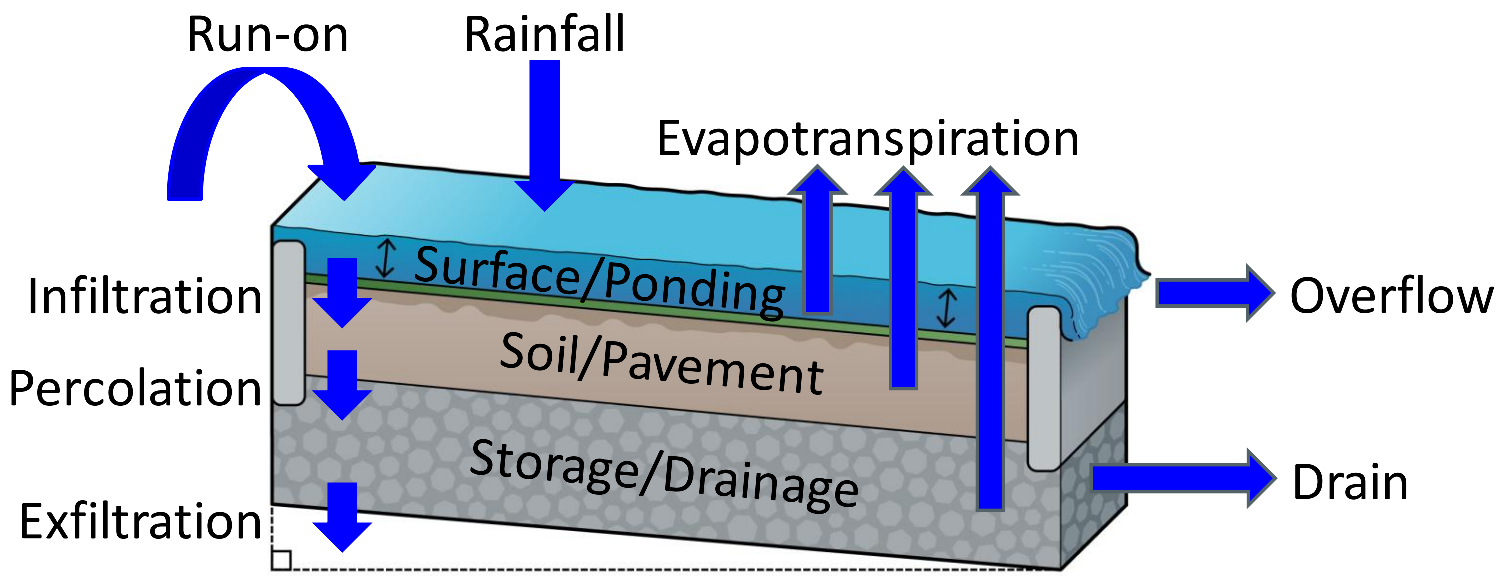
Green Roof



Bio-Retention Cell

Profiles in Storage





LID Process Layers

	Process Layer					
LID Control	**Surface**	**Pavement**	**Soil**	**Storage**	**Drain System**	**Drainage Mat**
Rain Barrel	✗	✗	✗	✓	✓	✗
Vegetative Swale	✓	✗	✗	✗	✗	✗
Infiltration Trench	✓	✗	✗	✓	(optional)	✗
Rain Garden	✓	✗	✓	✗	✗	✗
Bio-Retention Cell	✓	✗	✓	(optional)	(optional)	✗
Green Roof	✓	✗	✓	✗	✗	✓
Permeable Pavement	✓	✓	(optional)	✓	(optional)	✗
Roof Disconnection	✓	✗	✗	✗	✓	✗

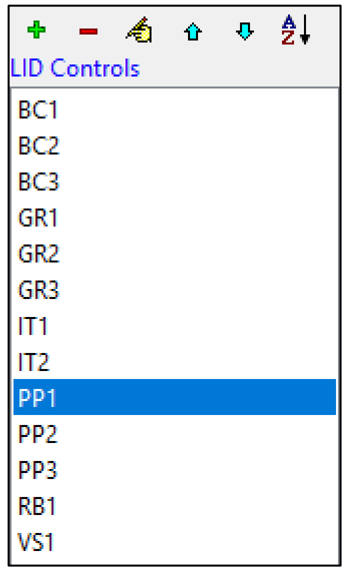
- What if your facility is not represented above?

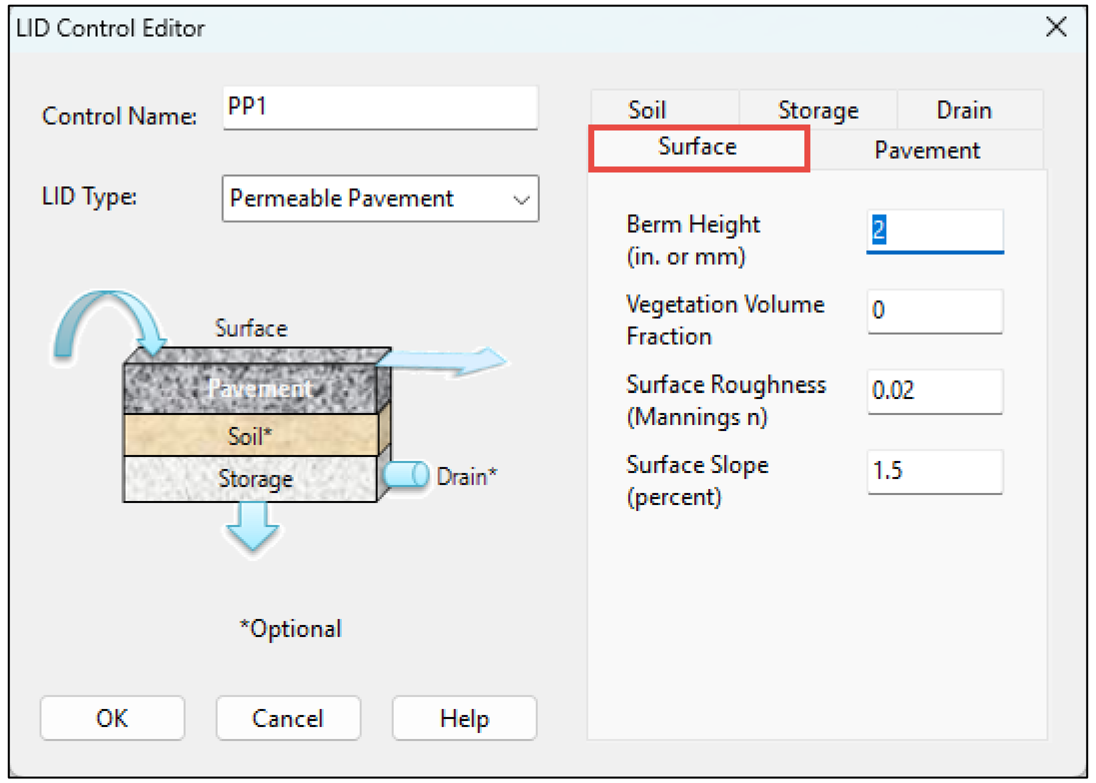
Green Infrastructure Facilities	Modeled as…
Street Planter	Bioretention Cell
Infiltration Gallery	Infiltration Trench (or explicitly in hydraulic model if overlying native soil)
Rainwater Harvesting System	Rain Barrel (or explicitly in hydraulic model if variable demands)
Roadside Ditching	Vegetative Swale (or explicitly in hydraulic model if check dams)
Rooftop Storage	Roof Disconnection
Parking Lot Storage	Equivalent roof disconnection (or explicitly in hydraulic model)
Modular Storage Tanks	Equivalent Infiltration trench (or explicitly in hydraulic model)
Etobicoke Exfiltration System	n/a - model explicitly in hydraulic model
Alternative Site Design	n/a - model explicitly in hydrology model
Turf Conversion	n/a - model explicitly in hydrology model
Urban Forestry Program	n/a - model explicitly in hydrology model

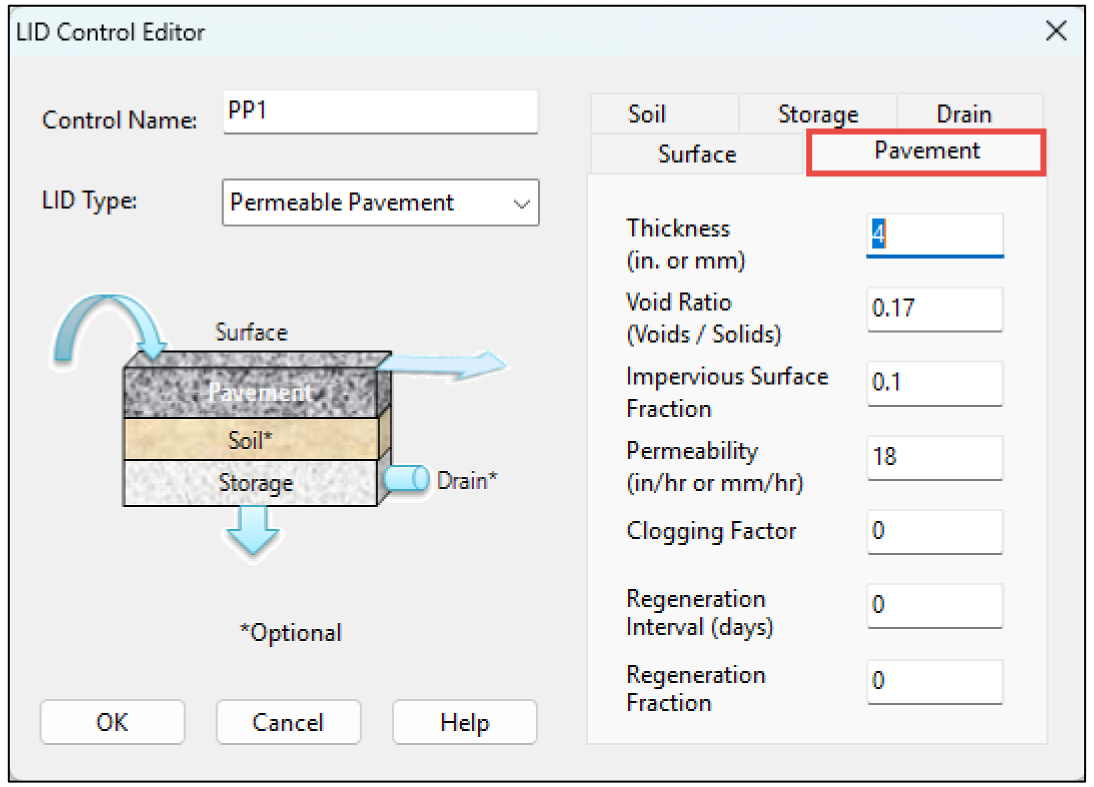
…and what about:

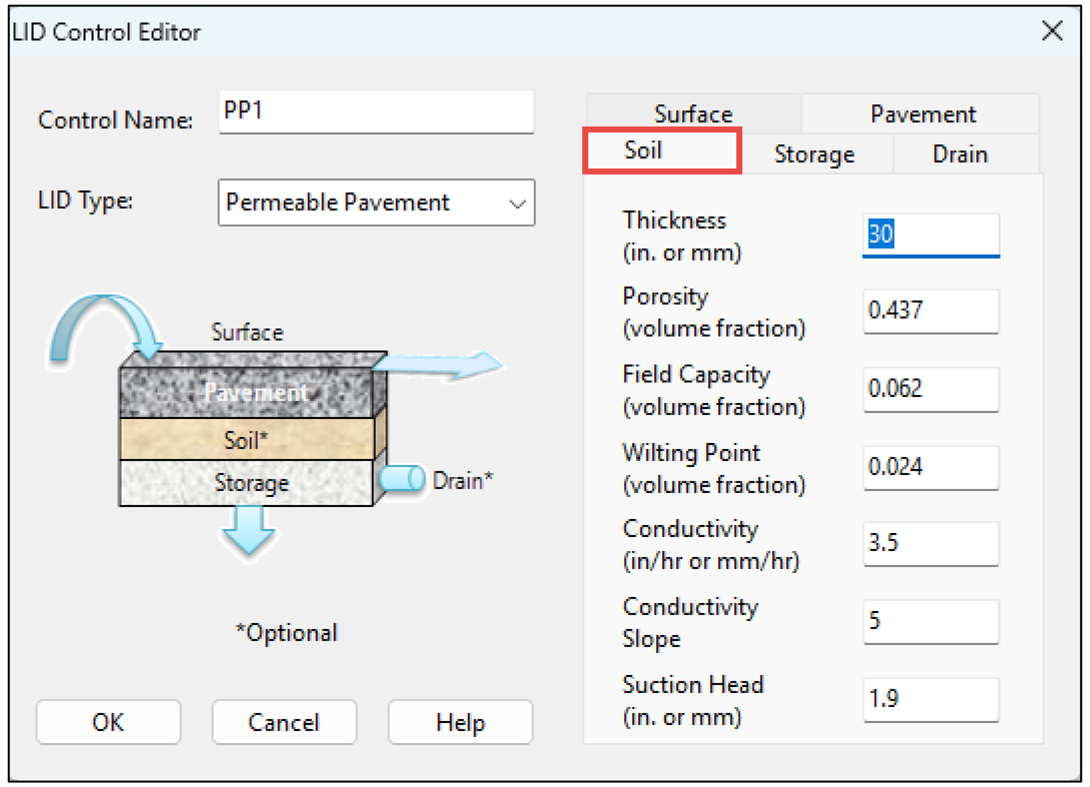
- Bioswales
- Resilient landscaping
- Soil cells
- Tree trenches

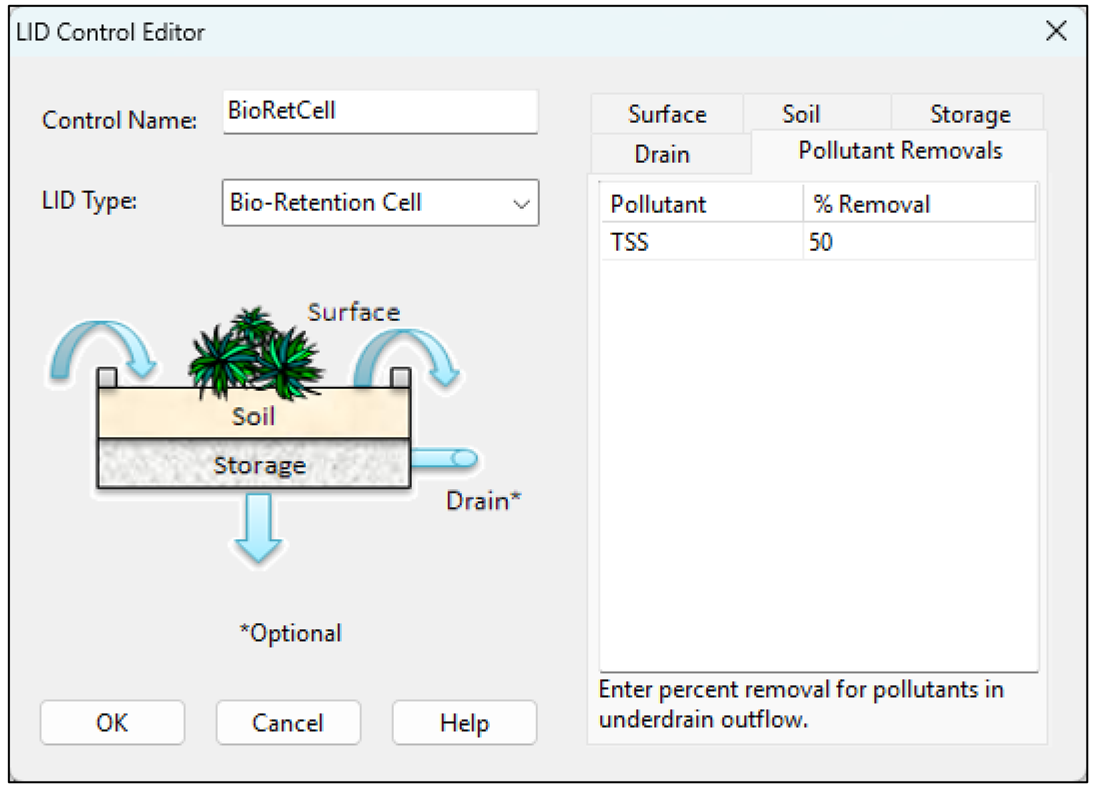
LID Process Layer Parameters

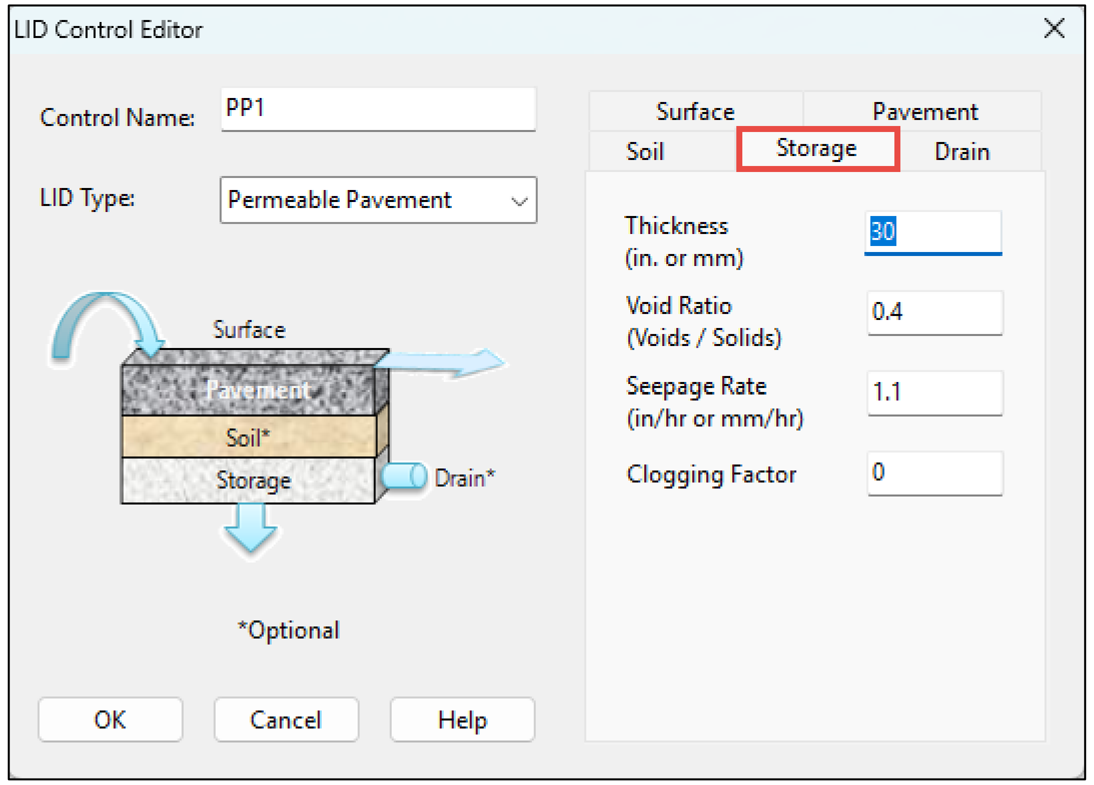


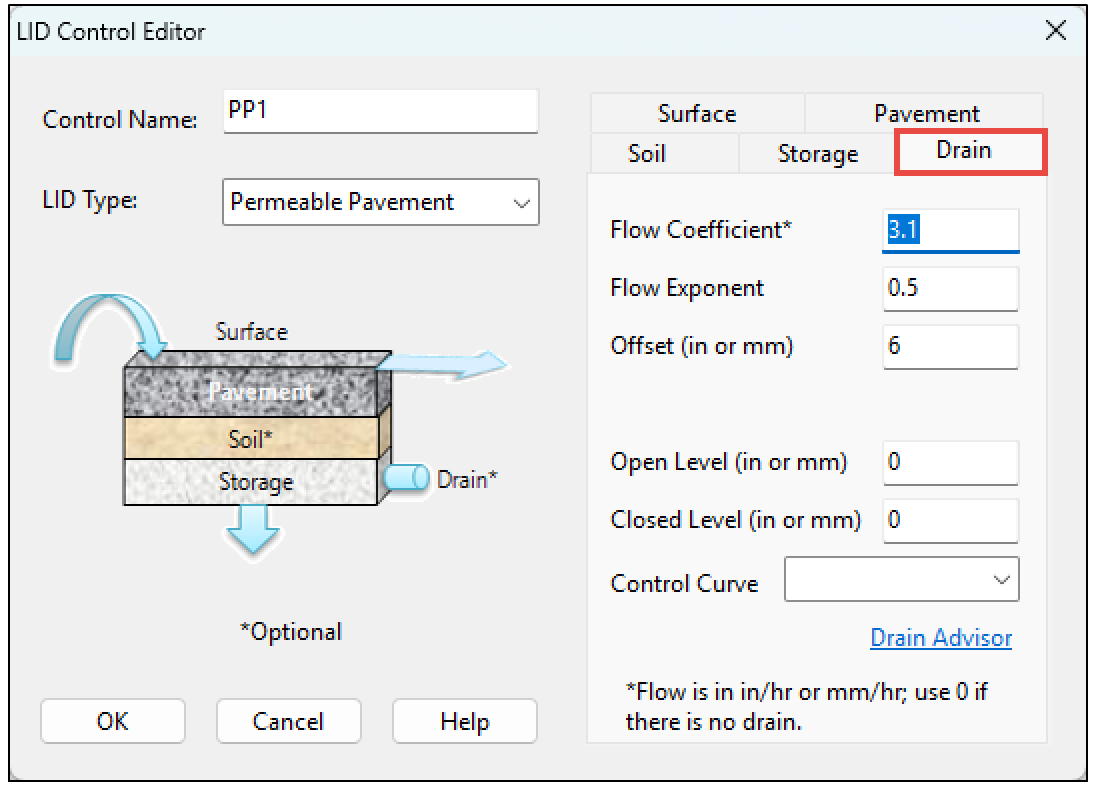






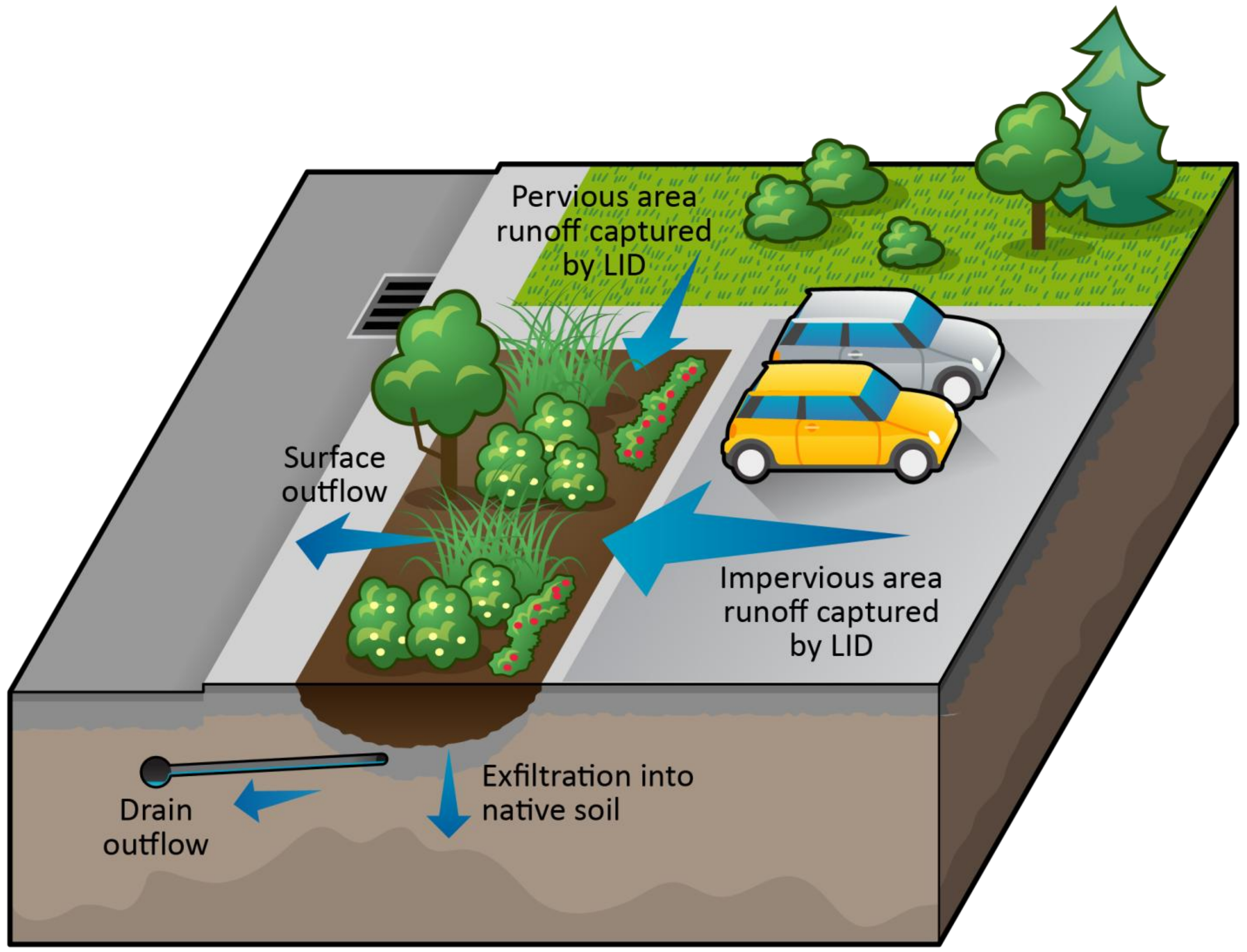


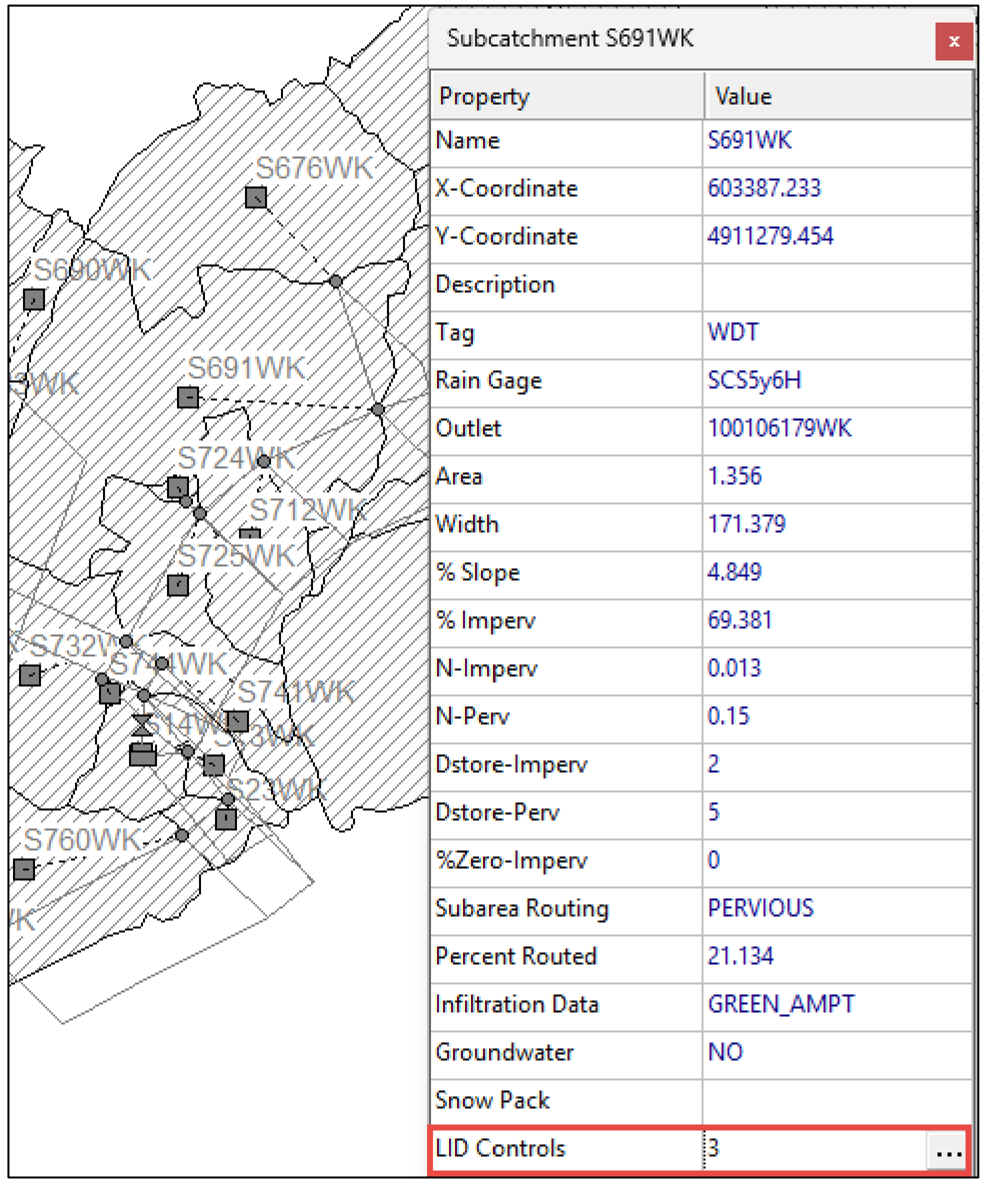




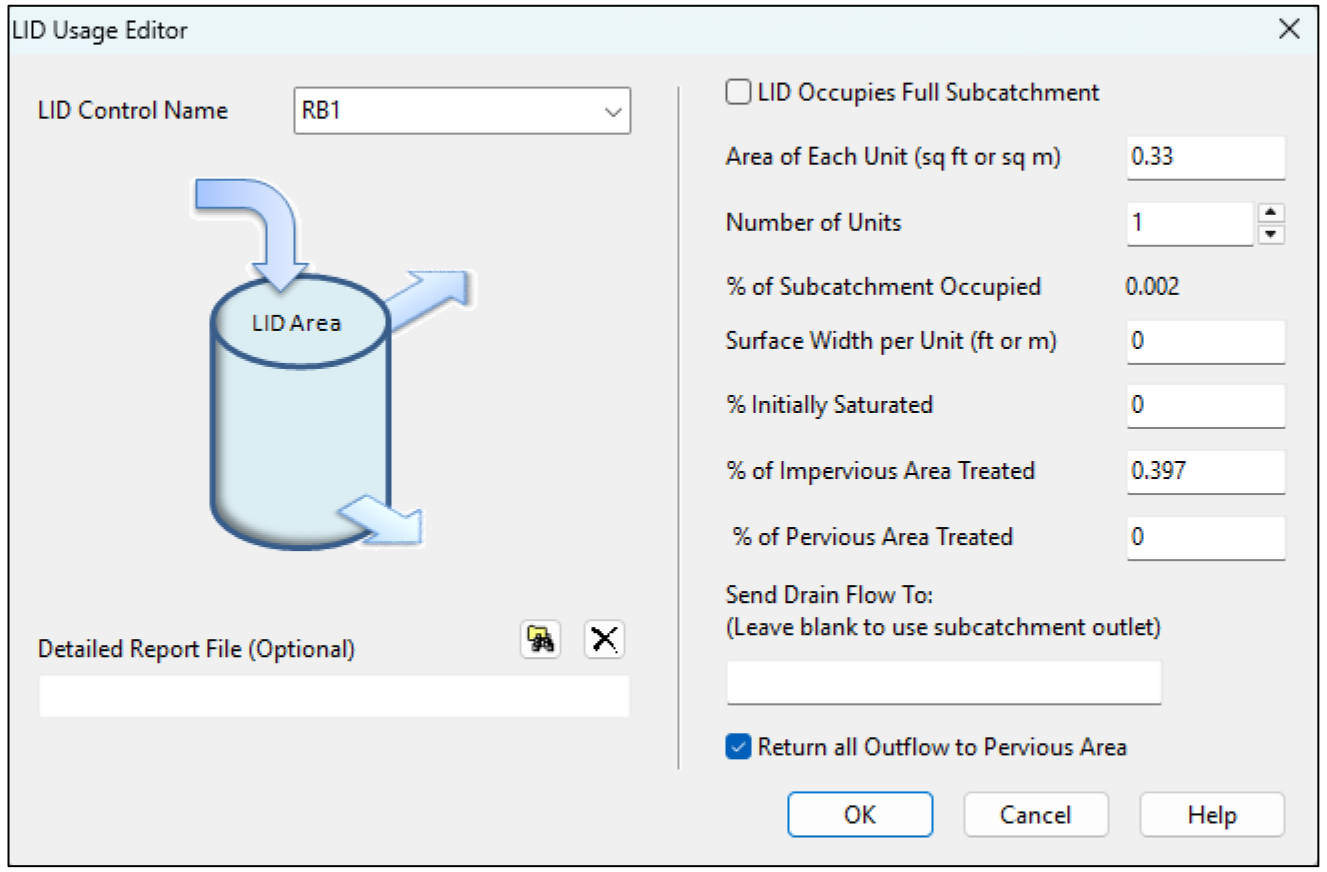
LID Usage

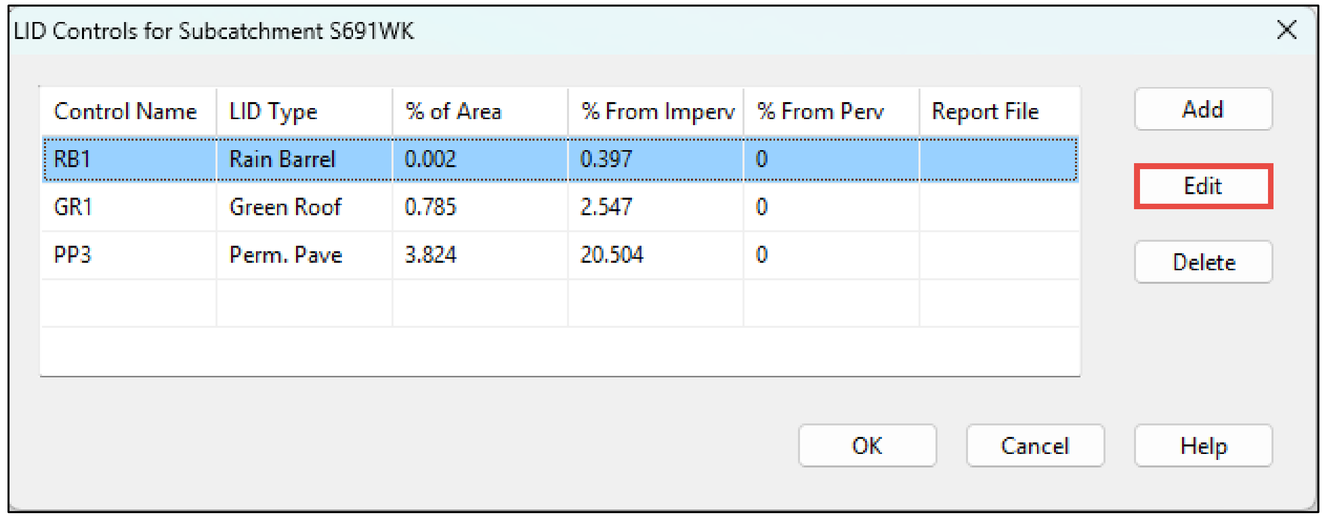
- Representing LID practices:
  - LID Controls Editor for depth-wise (profile) parameters
  - LID Usage Editor for footprint (plan view) parameters





Property	Value
Name	S691WK
X-Coordinate	603387.233
Y-Coordinate	4911279.454
Description	
Tag	WDT
Rain Gage	SCS5y6H
Outlet	100106179WK
Area	1.356
Width	171.379
% Slope	4.849
% Imperv	69.381
N-Imperv	0.013
N-Perv	0.15
Dstore-Imperv	2
Dstore-Perv	5
%Zero-Imperv	0
Subarea Routing	PERVIOUS
Percent Routed	21.134
Infiltration Data	GREEN_AMPT
Groundwater	NO
Snow Pack	
LID Controls	3

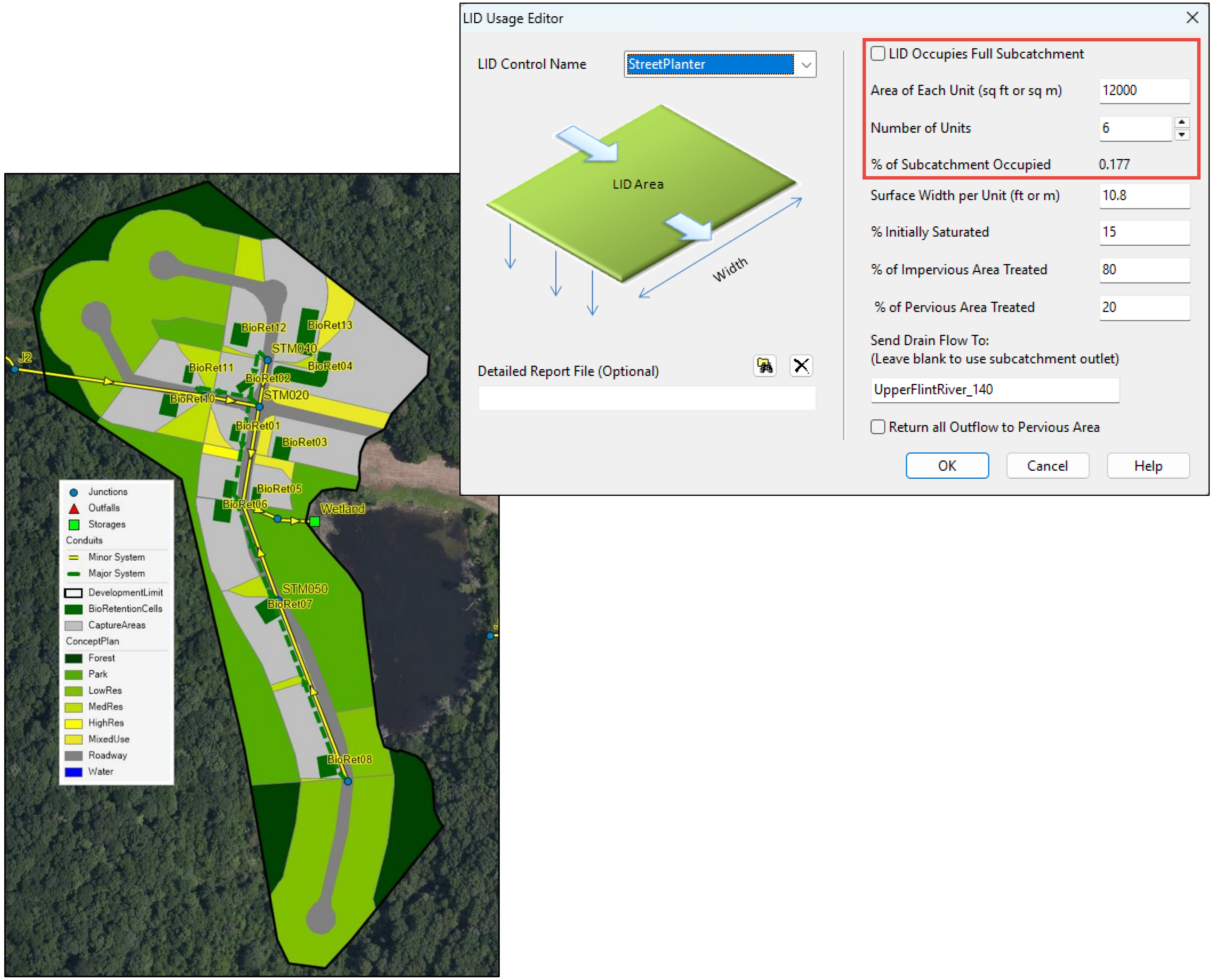




Control Name	LID Type	% of Area	% From Imperv	% From Perv	Report File
RB1	Rain Barrel	0.002	0.397	0	
GR1	Green Roof	0.785	2.547	0	
PP3	Perm. Pave	3.824	20.504	0	

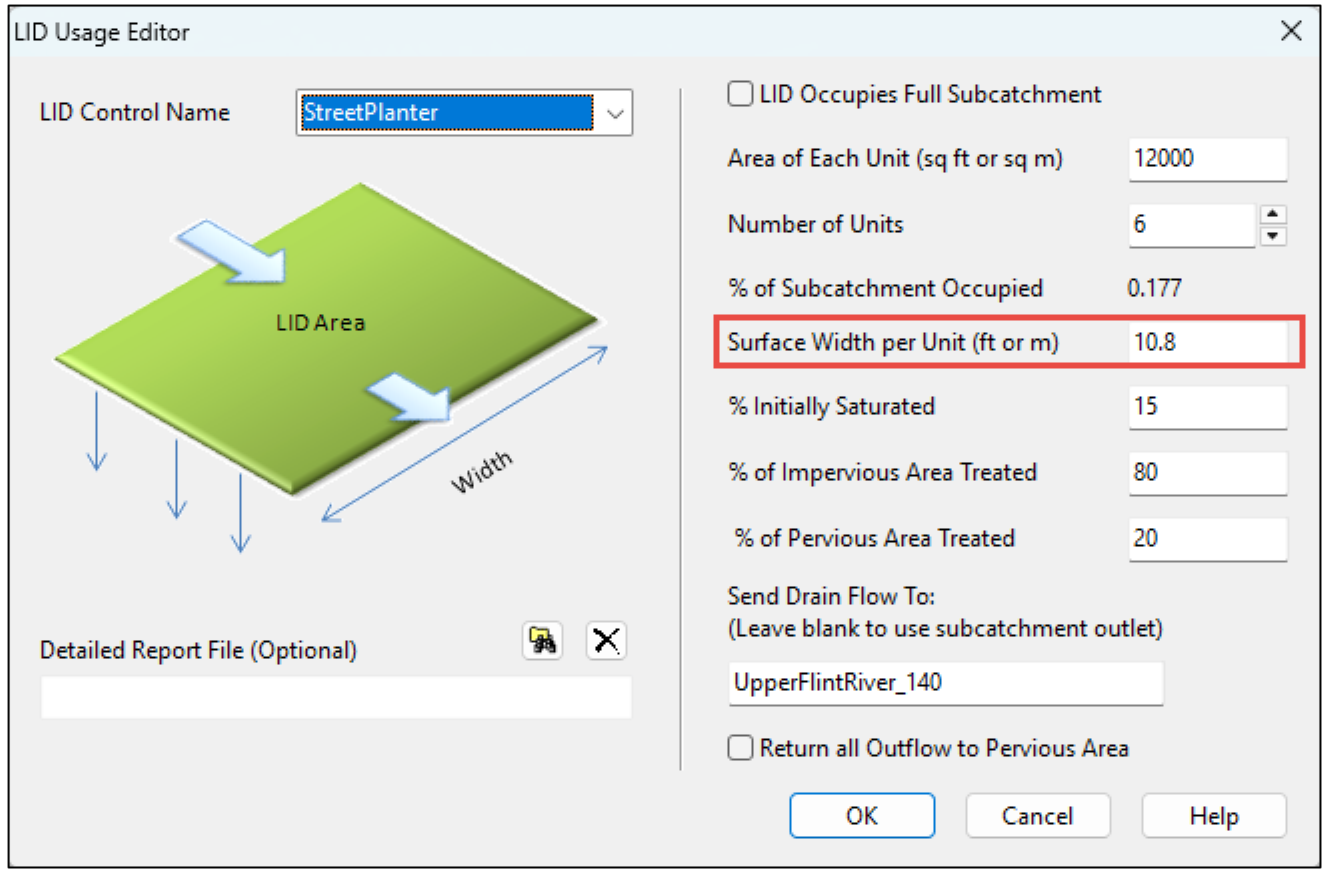
Area and Number of Units

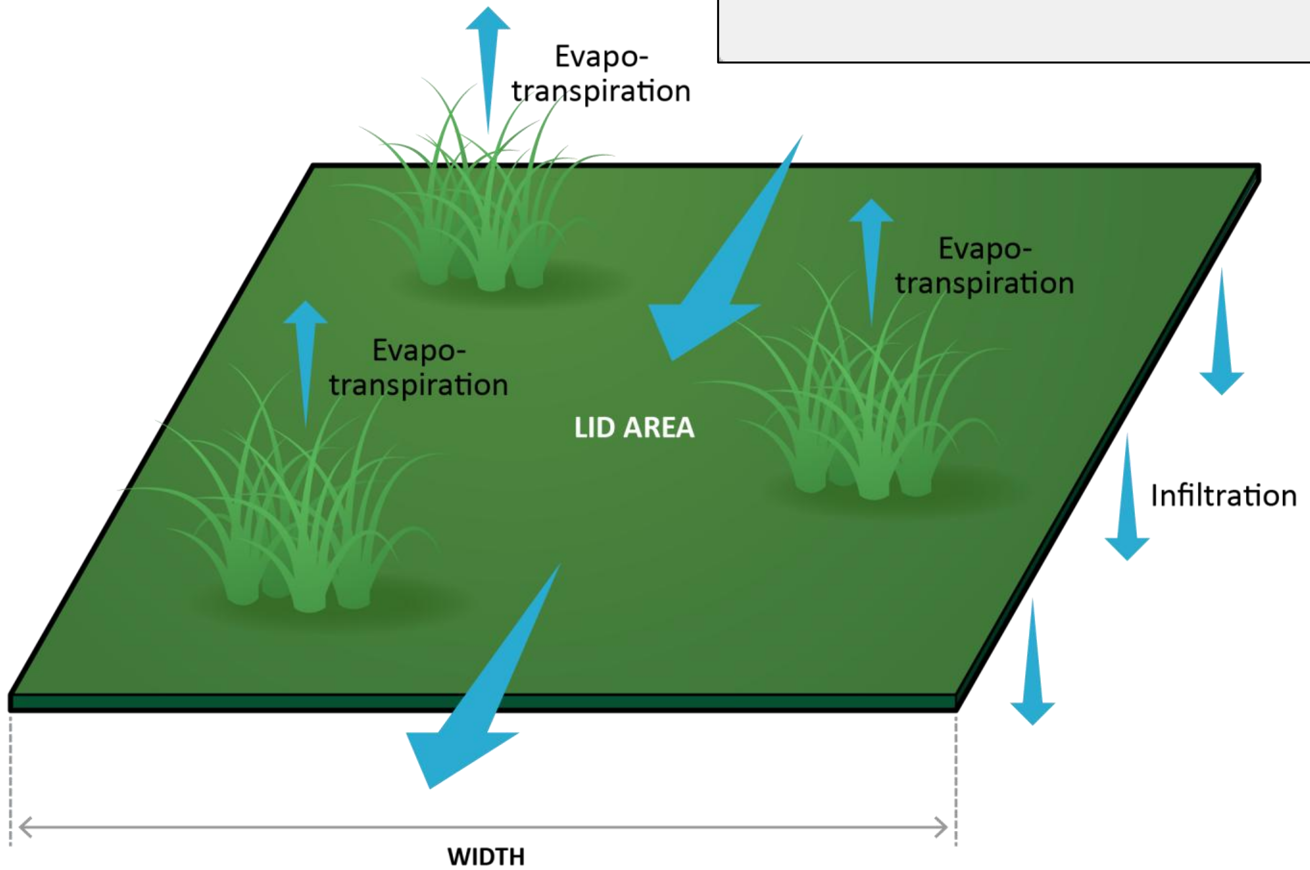
- Area of Each Unit and Number of Replicate Units must be specified
- Percentage of Subcatchment Occupied will be calculated
- If the LID fully occupies the subcatchment, then the LID footprint area will automatically be updated



Surface Width

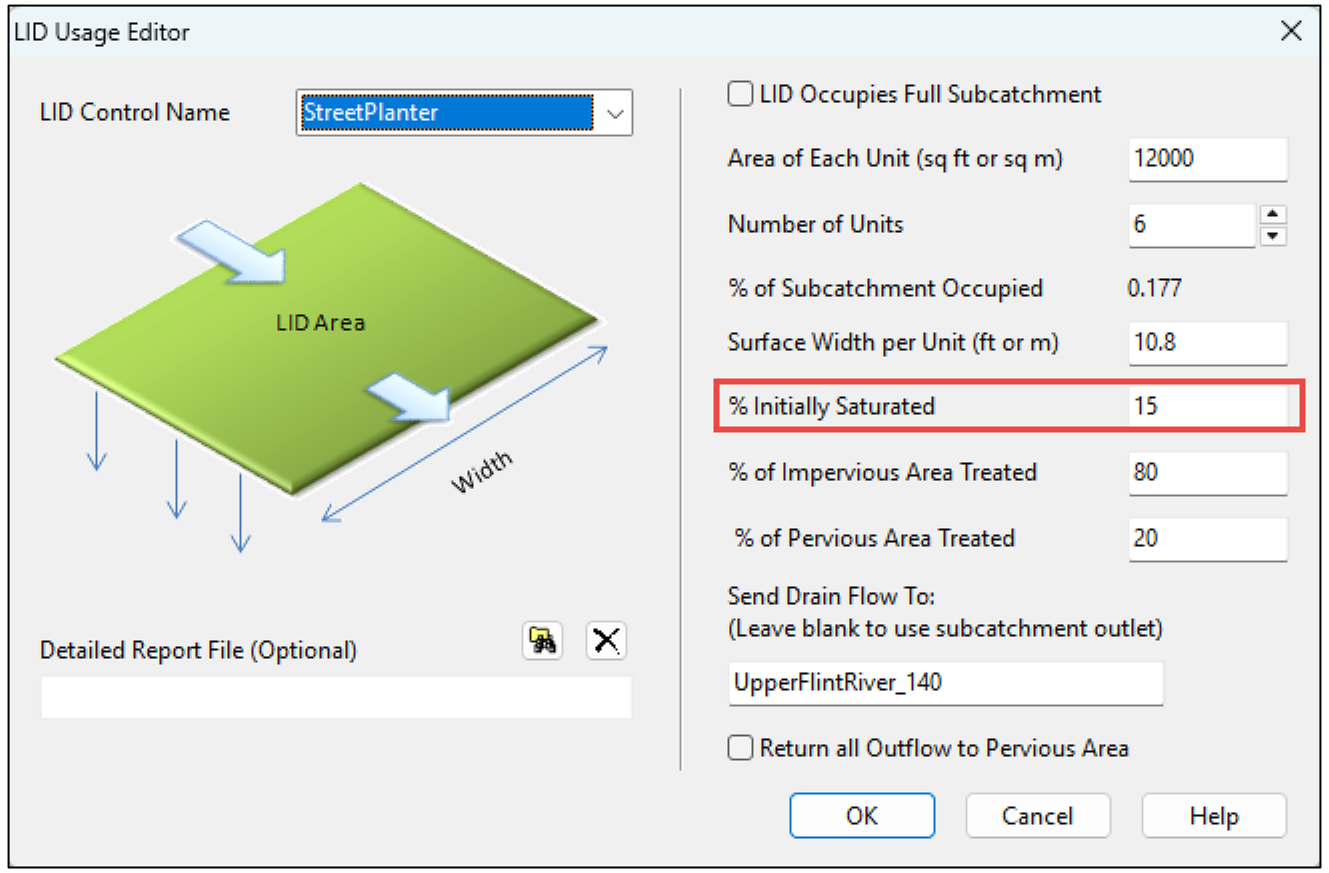
- Applies to LID controls that convey runoff by overland flow (not spill over berms or out of rain barrels)
- Surface Width is the width of the outflow face perpendicular to the direction of flow over the LID surface





Initial Saturation

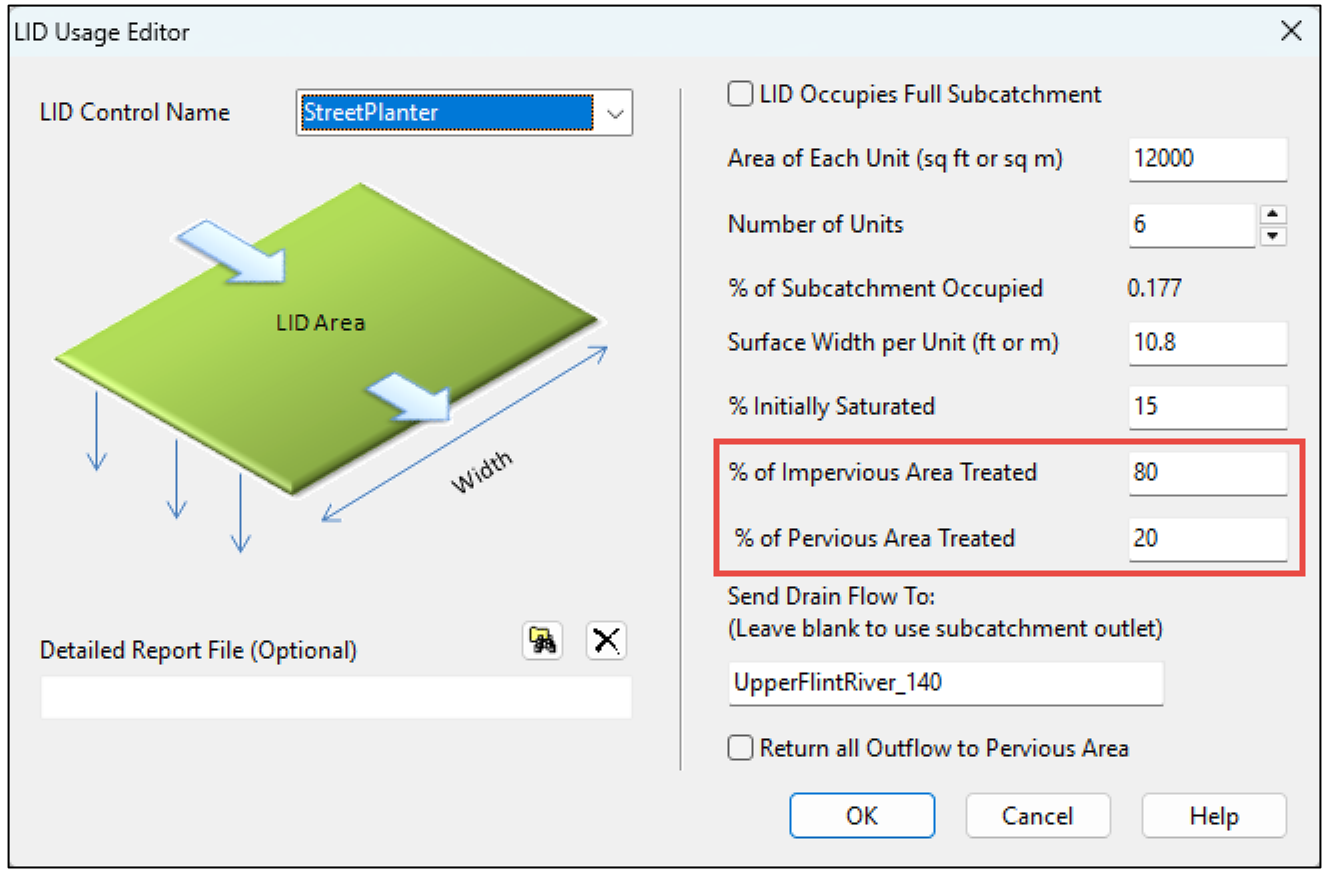
- In a soil layer, the Initial Saturation will reflect the percentage of void spaces in the soil that are filled
- In a storage layer, the Initial Saturation will represent the percent of the storage volume that is filled



LID Control Type	Saturation can be Specified
Rain barrel	✓
Vegetative swale	X
Infiltration trench	✓
Rain garden	✓
Bio-retention cell	✓
Green roof	✓
Permeable pavement	✓
Rooftop disconnection	X

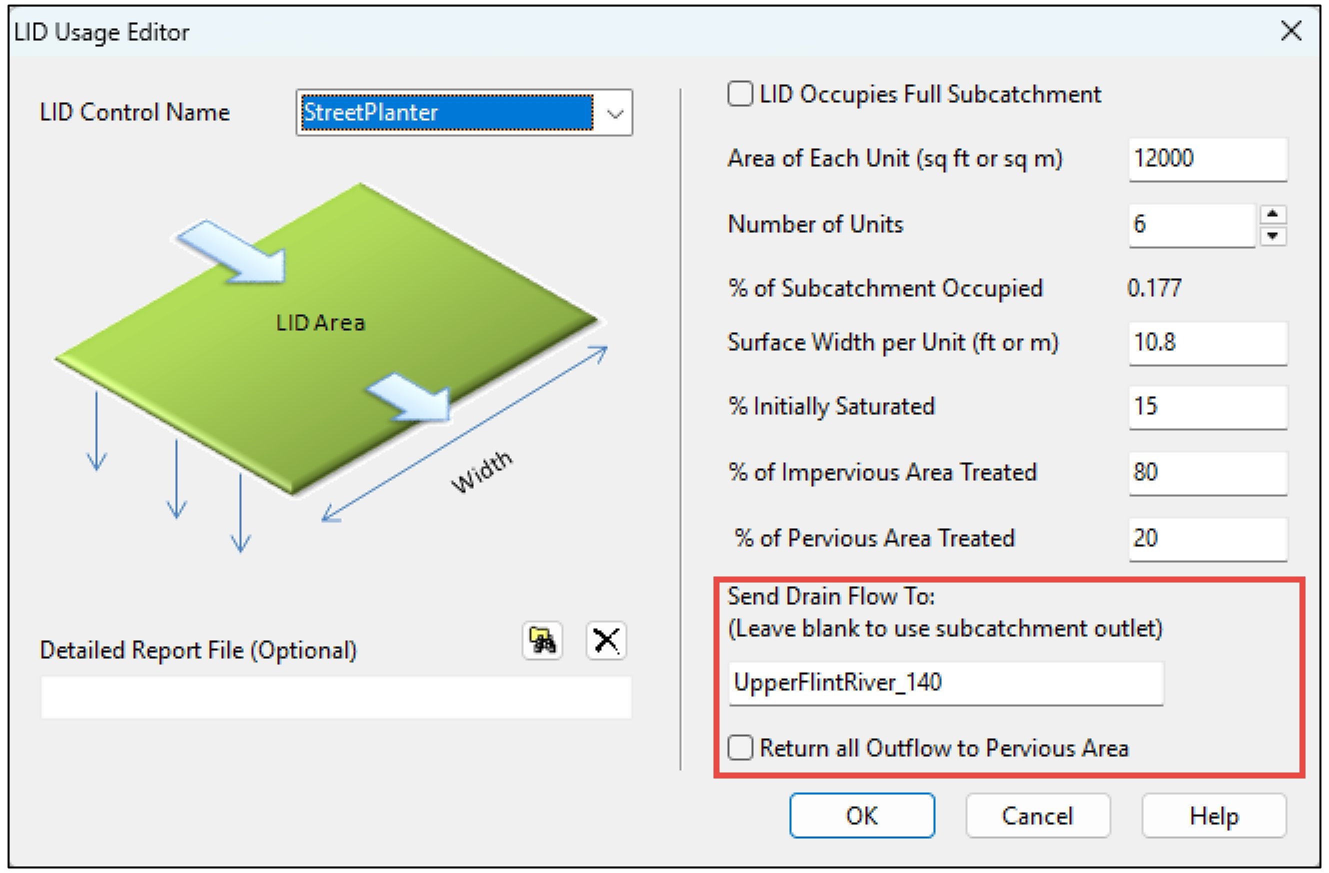
Treatment Area

- Impervious Area Treated: Impervious portion of the subcatchment non-LID area whose runoff is captured and discharged onto the LID
- Pervious Area Treated: Pervious portion of the subcatchment non-LID area whose runoff is captured and discharged onto the LID
- If LID unit treats only direct rainfall (i.e., green roof) then use 0 for both
- If LID takes up the entire subcatchment then these fields are ignored



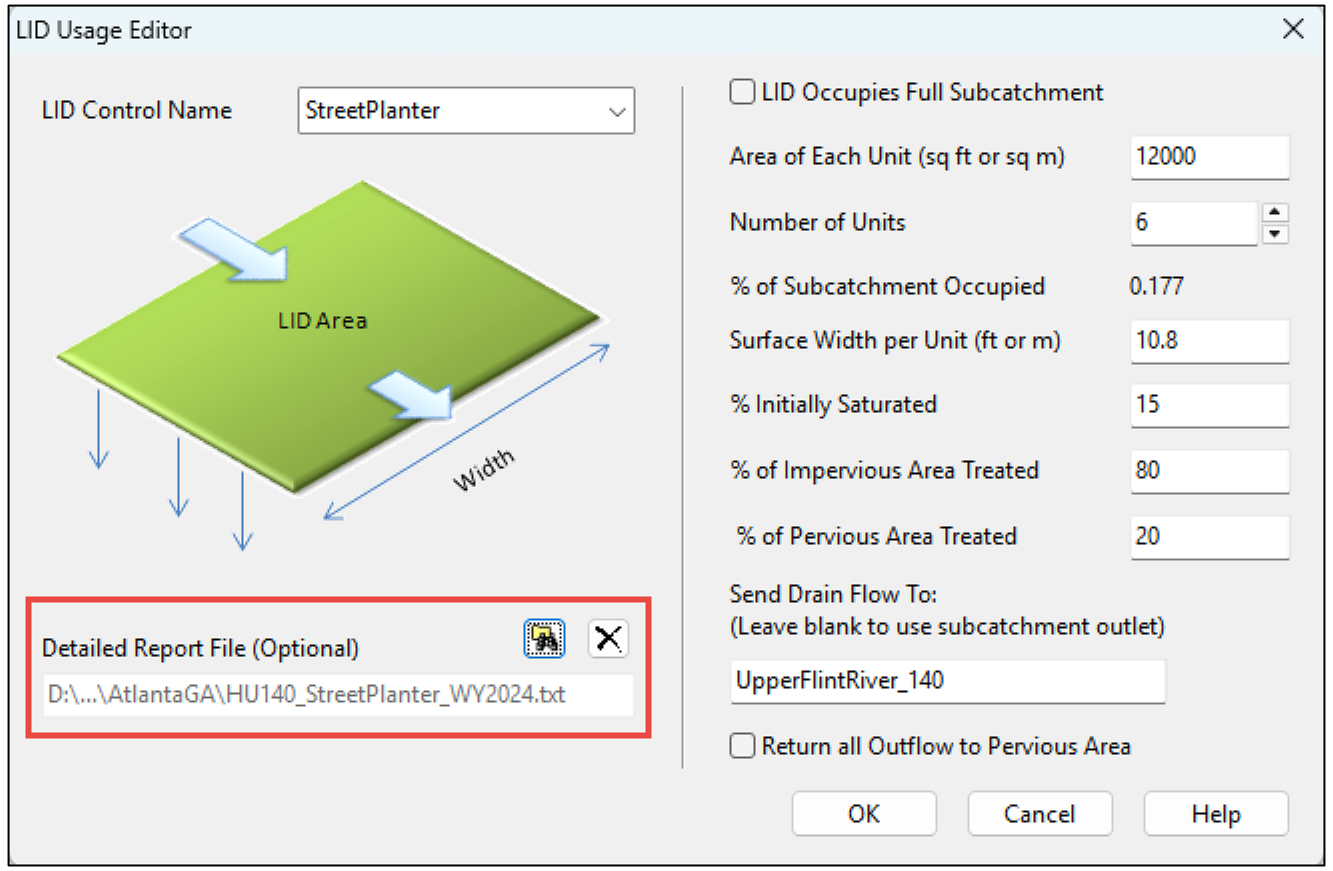
Drain Flow and Outflow

- To route flow from the underdrain to another node or subcatchment, enter the location at "Send Drain Flow To"
- If LID outflow is directed to a pervious portion of the subcatchment, check "Return all Outflow to Pervious Area"
- This option is only available for the outflow from rain barrels, green roofs and rooftop disconnection



Detailed Report File

- Check the option in the editor to create a report file just for LID processes
- The LID detailed report file (.txt file) provides time series of the internal flux rates and moisture levels computed for a LID control usage in a subcatchment
- These files can be opened in the Graph panel to view and analyze the results graphically and statistically



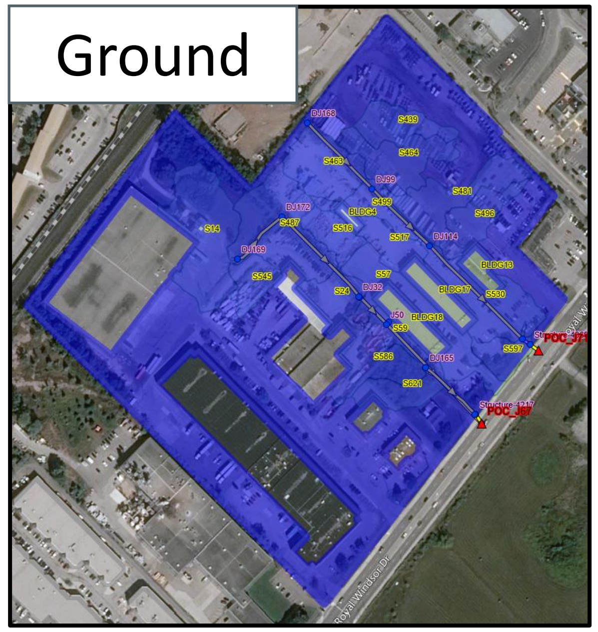
Source Area Opportunities

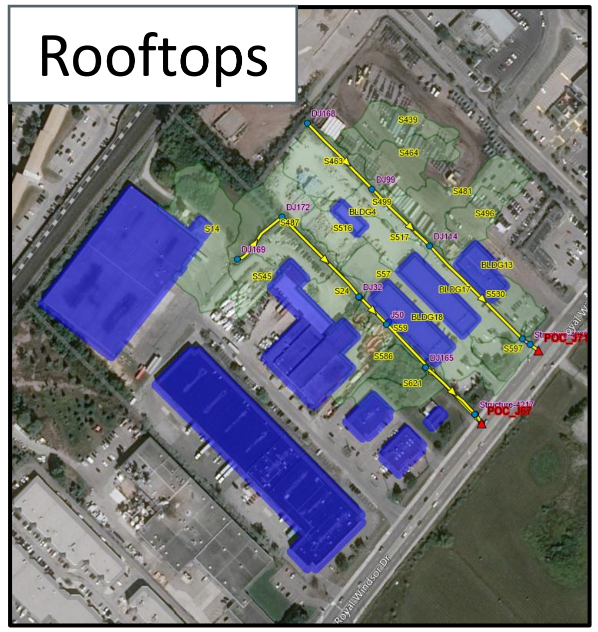
- Distinguish surface cover characteristics at relatively high level of detail
  - Think of hydrologic “source areas” rather than “land uses”
  - Also applies to water quality modeling (i.e., build-up and wash-off parameters)
  - Runoff/pollutant generation versus planning designation
- LID planning/design must consider:
  - Maximizing impervious source area capture and treatment
  - Feasible/practical opportunities to collect source area runoff (by gravity)
  - Realistic “uptake” and proper installation, operations, and maintenance

Example: Residential Rain Barrel Program

Impervious Area Treated = 1.6% =
25% (portion of rooftop served by rain barrels) ×
25% (rooftop impervious area) ×
25% (2 of 8 townhouse units have rain barrels) ×

LID Control Type	Primary Source Area
Rain Barrel	rooftops
Vegetative Swale	roadways
Infiltration Trench	roadways
Rain Garden	rooftops
Bioretention Cell	rooftops, roadways, parking areas
Green Roof	rooftops
Permeable Pavement	parking areas
Roof Disconnection	rooftops

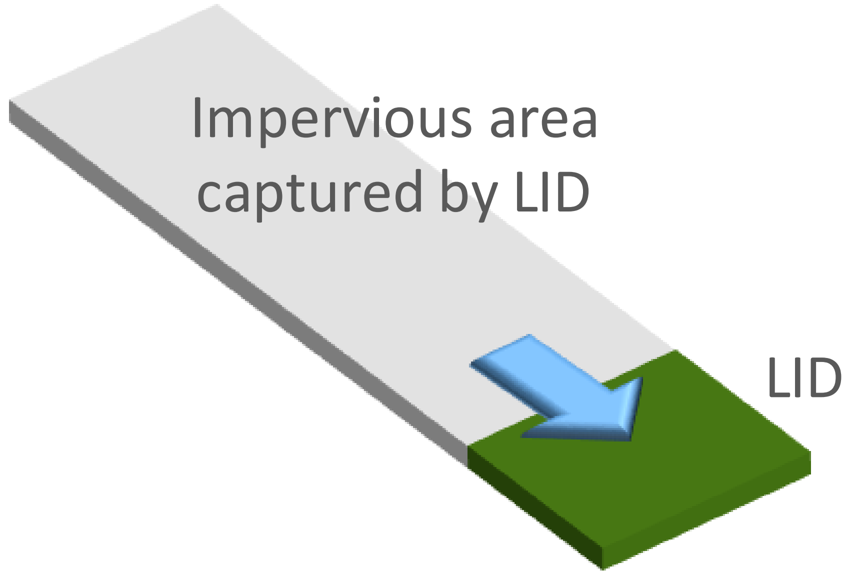




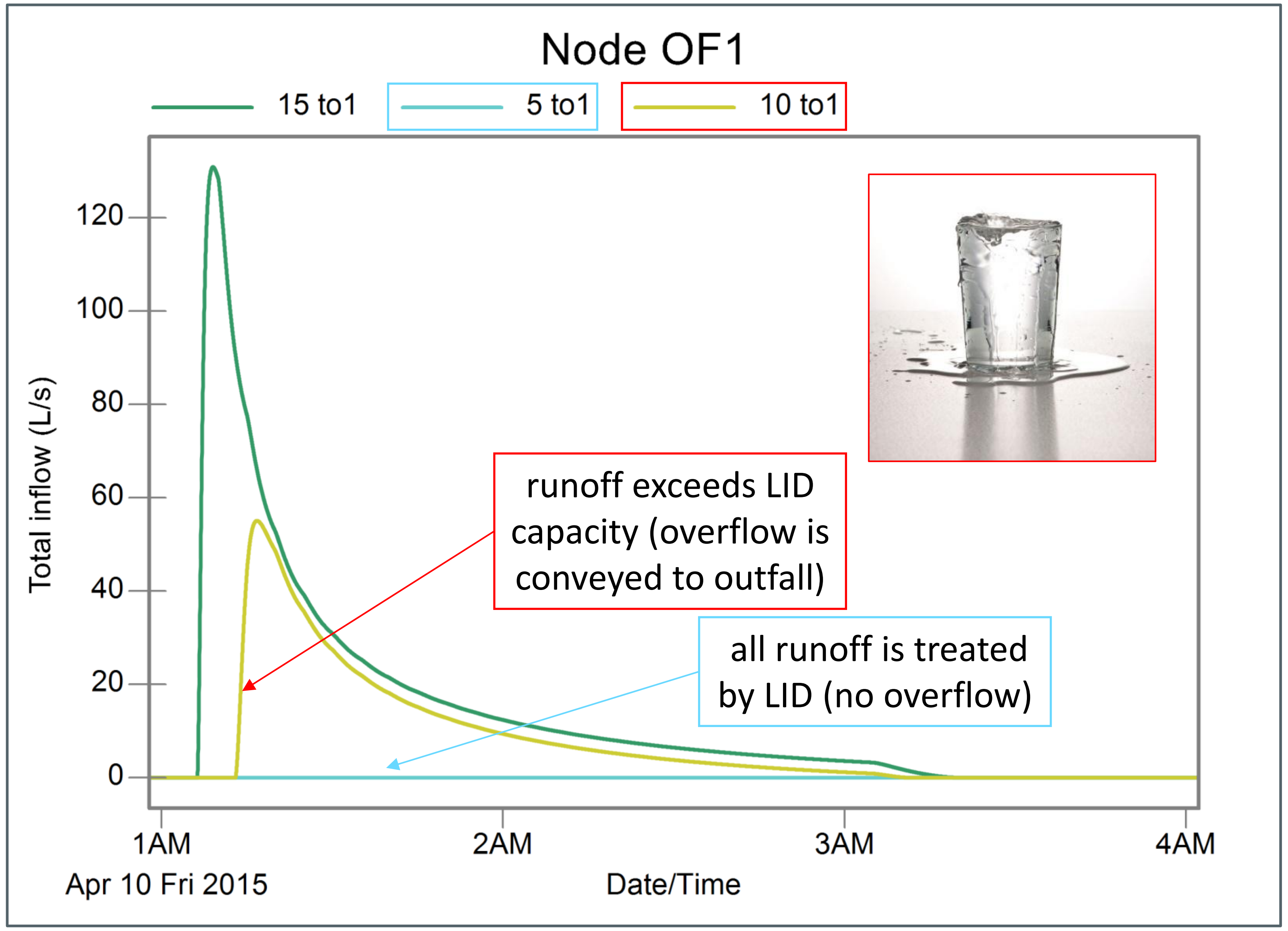
Design Tip: Capture Ratio

- Also known as "impervious area loading ratio" or "I/P ratio", quantifies the risk of over-loading an LID with too much impervious area

$$= \frac{\text{Subcatchment impervious area captured and treated}}{\text{LID footprint area}}$$

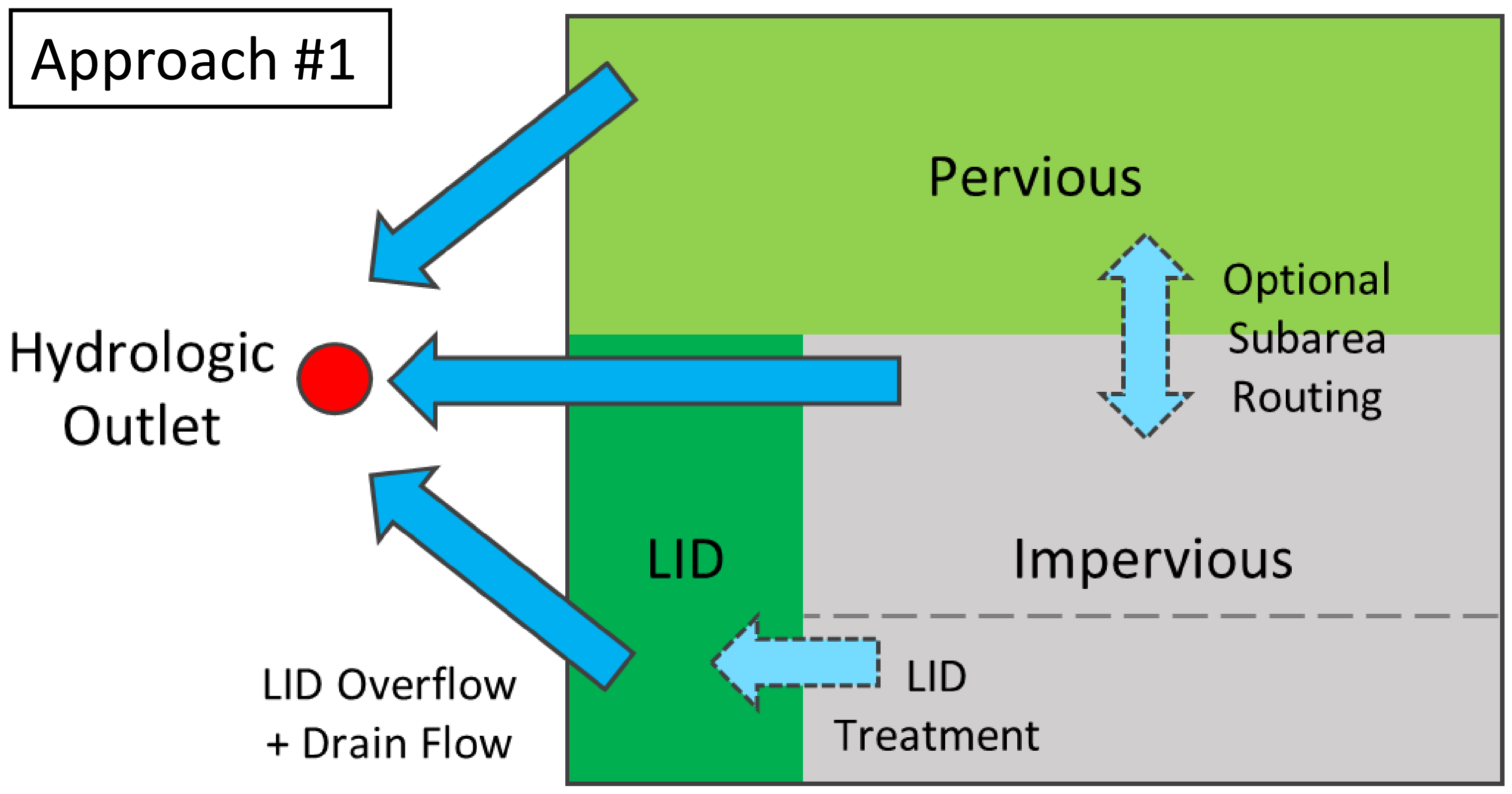


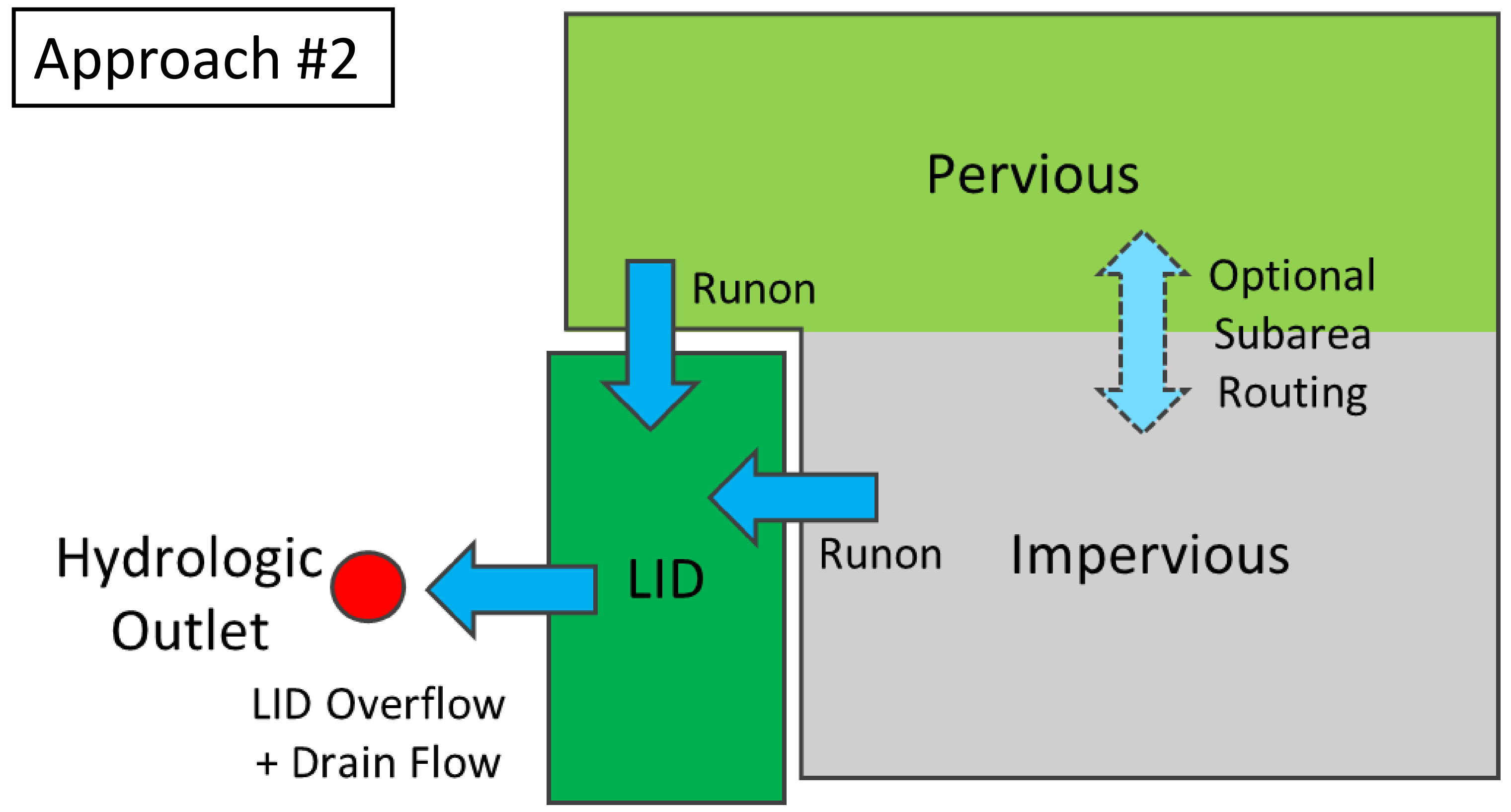
- Example: 1 ha site, 60% impervious captured by LID (6,000m^2 of impervious area)
  - Capture ratio = 5 to 1 (LID footprint = 1,200m^2)
  - Capture ratio = 10 to 1 (LID footprint = 600m^2)
  - Capture ratio = 15 to 1 (LID footprint = 400m^2)



LID Modeling Approaches

- Approach #1 (using the LID Module)
  - Within an existing "parent" subcatchment
  - Typically applied at a neighborhood scale
  - Allows evaluation of multiple LID in parallel
- Approach #2 (using the LID Module)
  - Subdivide parent into LID & non-LID areas
  - Typically applied at a lot/parcel/site scale
  - Allows evaluation of multiple LID in series
- Approach #3 (without the LID Module)
  - Model hydrology & hydraulics explicitly

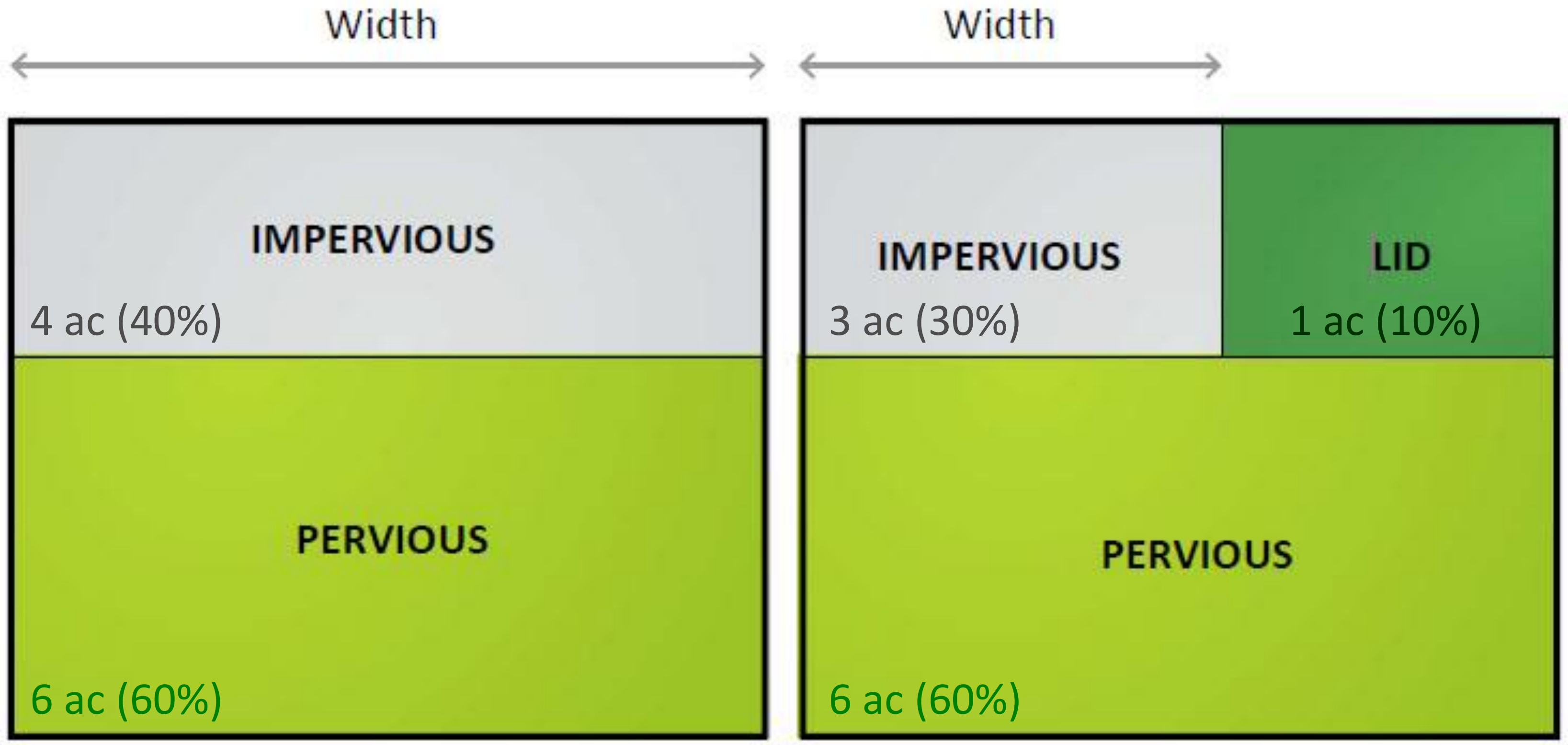




Recalculating Imperviousness

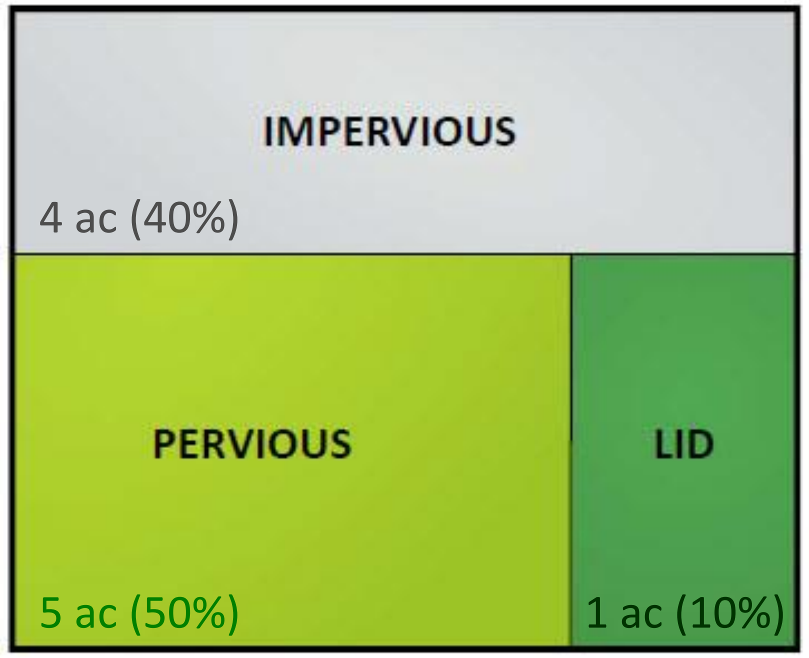
$$\%\text{Imp} = \frac{\text{Impervious area}}{\text{Non}-\text{LID area}}$$

- For LID within a subcatchment, adjust imperviousness so that it is impervious area remaining divided by non-LID area
- Overland flow width should also be adjusted since the LID area is not considered when calculating runoff
- Case 1: a 10-acre parent subcatchment with 40% imperviousness will be occupied by a 1-acre LID control (i.e., taking up 25% of the impervious portion)
- Case 2: same as Case 1, but LID control takes up 20% of the pervious portion



$$\%\text{Imp} = \frac{(100\% - 25\%) \times 4\text{ ac}}{10\text{ ac} - (25\% \times 4\text{ ac})} = \frac{3\text{ ac}}{9\text{ ac}} = 33\%$$

$$\%\text{Imp} = \frac{4\text{ ac}}{9\text{ ac}} = 44\%$$



Stormwater
Modeling Committee
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EWRI Congress 2025, EPA SWMM5 Workshop -- LID Modeling

Thank you for your attention…
any questions?

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