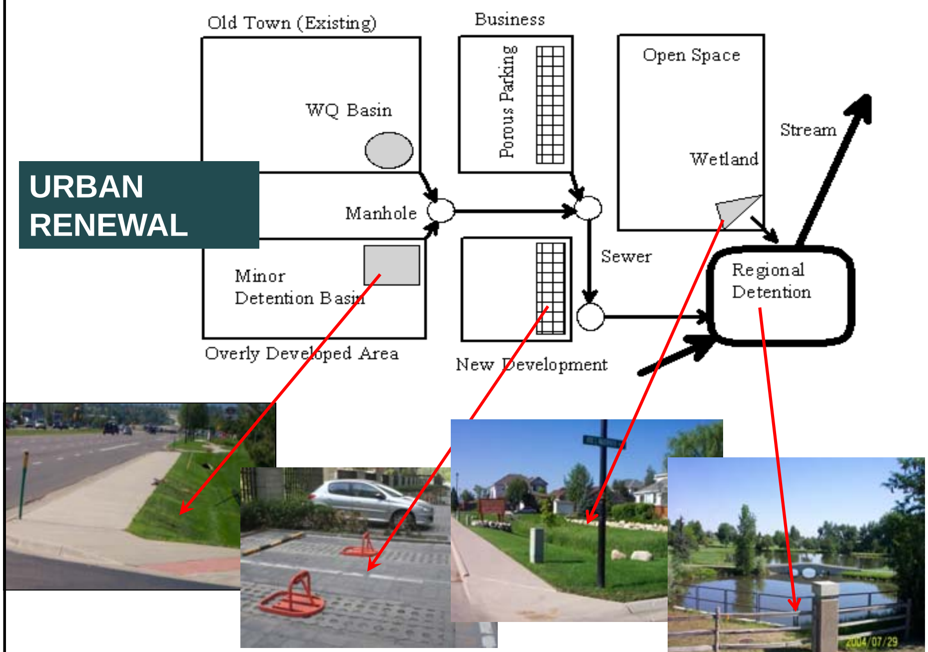
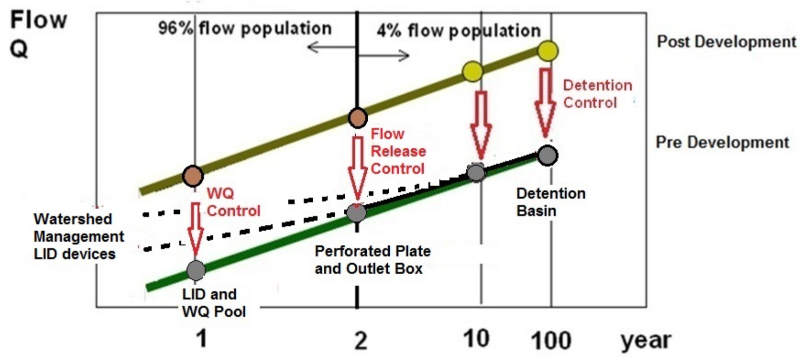
SWMM LIDs

Dr. James C.Y. Guo,
Professor and P.E., Civil Engineering, U. of Colorado Denver

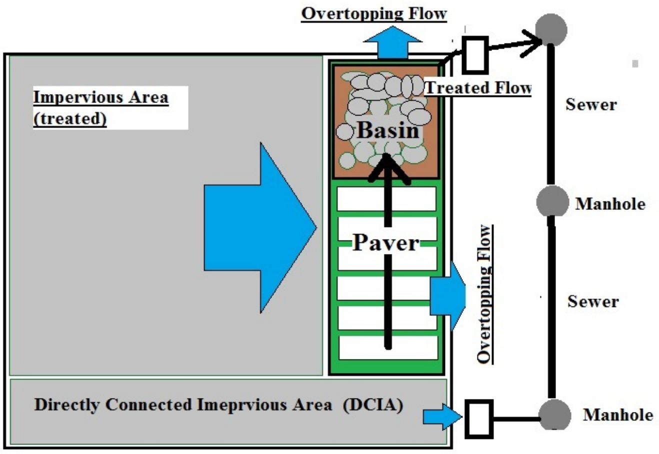
URBAN RENEWAL



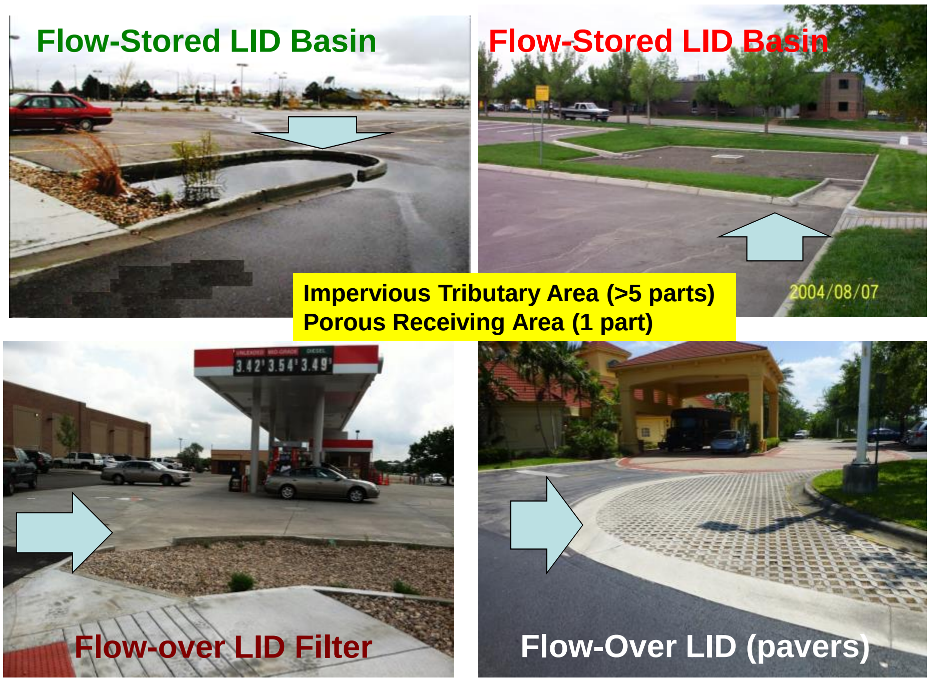
Why do we need LID?



Layout of LID Site – Small Lot (1-5 hectares)



Total area is divided into Impervious area, LID area, and DCIA area
Impervious area drains onto the LID area, the area ratio>4.
Not all impervious area can be connected to a LID area



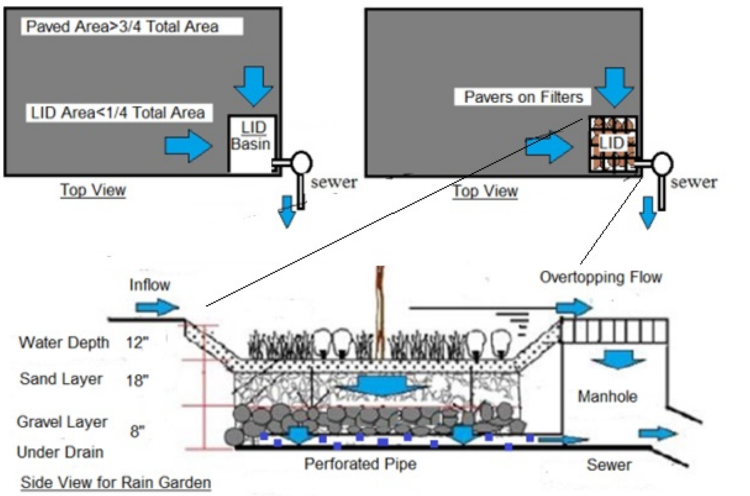
What is wrong with these LID sites?

Soft or Hard Surface?
Loading Strength?

Flow-stored LID = surface reservoir into sand filter

Storage LID – Volume-stored

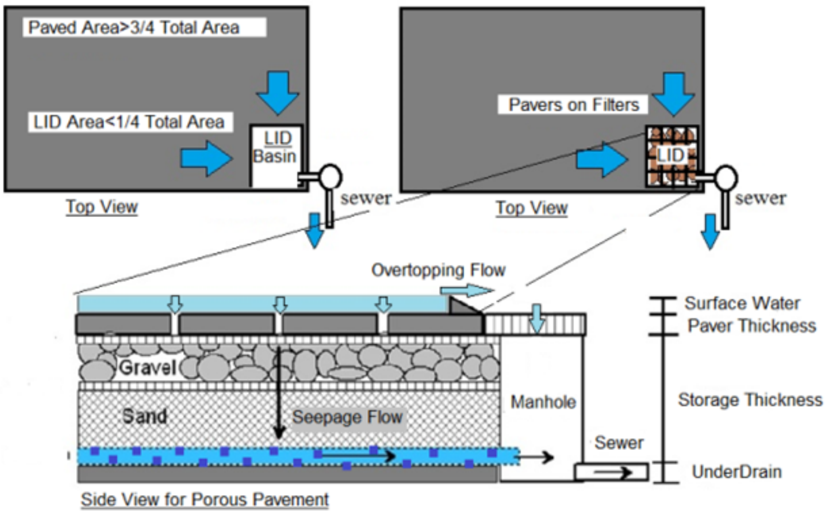
Rain Garden, Bio-Retention, Sand Filter , Infiltration Basin, and Rain Barrel



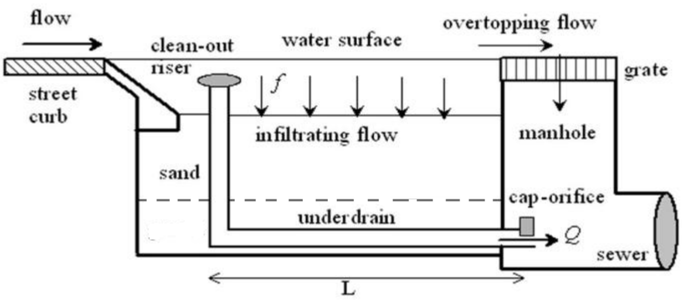
Flow-over LID = gravel reservoir into sand filter

<u>Conveyance LID –Flow over</u>

Porous Block Paver, Porous Concrete, Pervious Asphalt Surfaces



Construction of LID Rain Garden

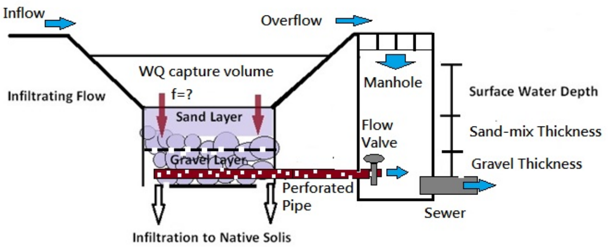


ExampleConstruction of RAIN GARDEN

New construction at a shopping mall area, Denver, Colorado

Basic Design Parameters and Considerations

Design Parameters
1. Drain Time
2. WQCV
3. Infiltration Rate
4. Sand-mix Layer
5. Gavel Layer
6. Flow Valve
7. Clogging Effect



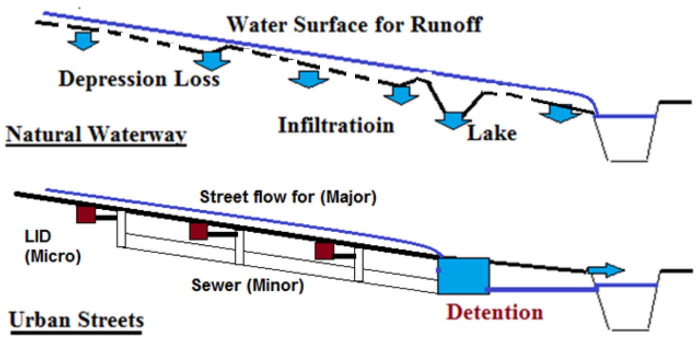
Design Considerations
(Q-1) How often it rains?
(Q-2) How much runoff volume shall be stored? how big is big enough?
(Q-3) How fast to drain the stored water? how long is long enough for WQ?
(Q-4) How to control the flow release rate?
(Q-5) How to design the overflow bypass?
(Q-5) Is infiltration on the land surface = seepage rate through subsurface ?
(Q-6) How to evaluate the effectiveness?
(Q-7) How to assess the clogging effect?

What is the proper design volume for LID?
What is the proper design volume for Detention?

The major difference in watershed hydrology between the pre- and post-development is the amount of hydro losses. How to compensate the hydro loss after the development?

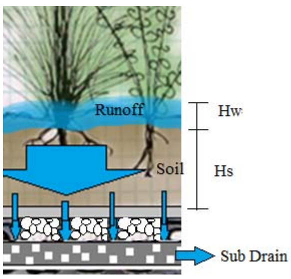
(1) On site LID storage volume = depression loss = 0.4 inch

(2) At the outfall point, the detention volume = infiltration loss = 1 to 2 inches



Example of Flat-Bed Green Roof Design
How thick the soil layer is (water absorption) ?

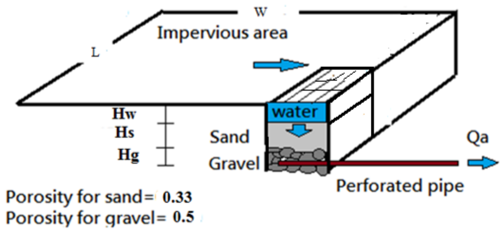
Vertical Profile



Soil Depth for Green Roof

Set WQCV =Depression loss= 0.4 inch, Soil Porosity =0.25, Initial soil water content =0.10. So the required soil depth = 0.4/(0.25-0.10) = 3.0 inch

LID Example



Total area A= L x W= 200 x 150 = 30,000 ft^2
Required on-site LID storage volume = 0.5 inch *30,000 ft ^{2}= 1250 ft^3
LID area = porous area = 50 *25=1250 ft^2
On-surface water storage depth Hw = 1250 ft^3/1250 ft^2=1.0 ft = 12 inch
Set the porosity for sand layer=0.33 and sand layer thickness Hs = 24 inch
Set the porosity for gravel layer=0.50 and gravel layer thickness Hg = 8 inch
Underground water storage depth= 0.33*24+0.50*8=12 inch
Set the drain time = 12 hr
Infiltration rate = water storage depth/drain time=12 inch/12 hr=1.0 inch/hr
How to design the sand-mix to have an infiltration rate at 1.0 inch/hr?

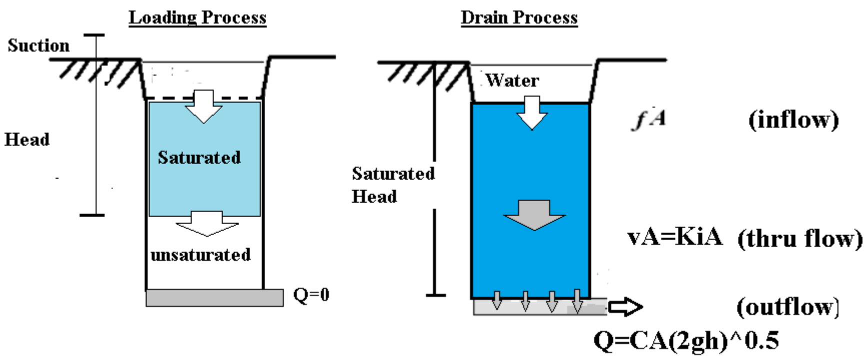
Design Consideration for LID site

- Develop on-site drainage under a known regional master plan
- Drain impervious areas onto pervious areas for source control
- Choose a % of flow interception along the flow path
- Size the proposed LID to compensate the pre-development hydro loss
  - Req'd Storage Volume =WQCV x Watershed Area
  - Surface Storage Volume = water depth x LID Pond Area
  - Subsurface Storage V= sand thickness x porosity + gravel x porosity
- Estimate the infiltration rate and drain time (Not EASY)
- Evaluate the proposed LID's performance by a long term simulation
- Adjust the drain time with a cap-orifice
- Confirm the proposed LID can preserve the watershed regime in terms of flow frequency and duration curves.
- Evaluate the proposed LID on peak flow reduction
- Add a detention system if more flow reduction is needed.

Laboratory Tests on Soil Mix and Infiltration Rate

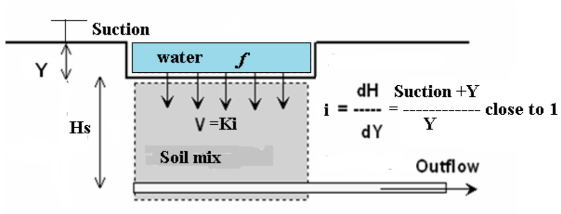
Infiltration Rate =fct (Mix of Sand, Compost, Others etc, and Clogging Effect)

Infiltrating Flow Hydraulics



Seepage flow = min (inflow, thru flow, outflow)

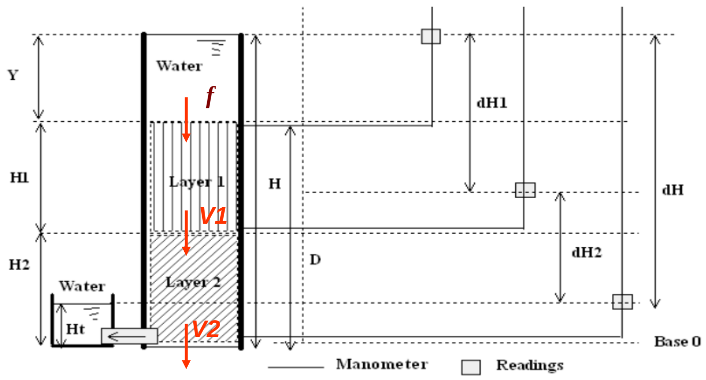
OPERATION OF INFILTRATING Detention Basin



- **Unsaturated Operation (Filling process)**
  infiltrating flow stored in the subsurface reservoir (soils)
  one-ft water in the basin = 4-ft soils if the soil porosity =25%
- **Saturated Operation (Depletion process)**
  Infiltrating flow through the saturated column of soils
  infiltrating flow *f* on the land surface
  seepage flow V through the soil layer V = Ki

- **Example:** *f* = 4 inch/hr on surface, V = 2 inch/hr through soils, and Q=3 inch/hr at the exit of sub drain pipe
  f > Q>V , so the flow capacity is dictated by V
  The entire system is backed up and results in
  (a) standing water on the surface and
  (b) water mounding in the subsurface

Seepage Flow Hydraulics V=Ki = K (i=1)

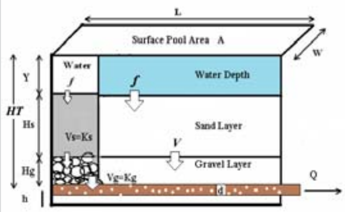


Basic Principles for Saturated Operation (Seepage Flow)
For the selected drain time T_d and water quality control volume, WQCV

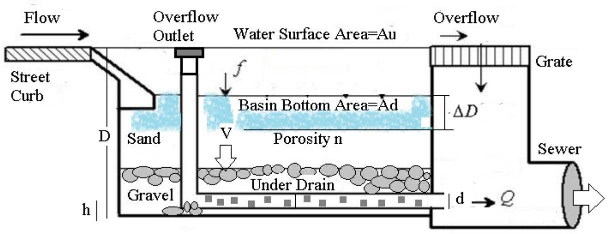
(1) Set water Depth — Y=12”
(2) Sub-layer Thickness — D = H1+H2 =18” + 8”
(3) Flow Continuity — $f = V_1 = V_2$ (>1”/hr)
(4) Energy Consumption — $dH_1 + dH_2 = D+Y$ (Ht=0)

A. Surface Storage Basin In Bio-Retention)Porous Landscaping Basin)			
Surface Area for LID Unit	A-LID	1,500.0	sq ft
Water depth in the surface basin	Y=	12.00	inches
B) Sub-Base Geometry for Two-Layered LID Basin			
Thickness of Upper Sand Layer	Hs=	18.00	inches
Hydraulic Conductivity of Sand Layer	Ks=	2.50	inch/hr
Porosity for Upper Sand Layer	Pore-s=	35.00	percent
Thickness of Lower Gravel Layer	Hg=	8.00	inches
Conductivity of Lower Gravel Layer	Kg=	25.00	inch/hr
Porosity for Lower Gravel Layer	Pore-g=	40.00	percent
Water storage Depth=Y+Hg*Pore-g+Hs*Pore-s	D-water=	21.50	inches >>
C) Enter the Design Infiltration Rate	Guess *f* =	**0.99**	**inch/hr**
Seepageg Flow through Porous Pavement Area= f * Ap	Q=	0.0343	cubic ft
Total Energy or Headwater Depth available =Y+Hg+Hs	HT=	38.00	inches
Energy Loss through Upper Layer =Is*Hs= f/Ks * Hs	dHs=	7.11	inches
Energy Loss through Lower Layer =Ig*Hg= f/ Kg * Hg	dHg=	0.32	inches
D) Analysis of Pipe Flow through Perforated Pipe			
Subdrain Pipe Diameter	d=	2.25	inches
Subdrain Pipe Length	L=	100.00	feet
Subdrain Manning's Roughness	N=	0.025	
Subdrain Pipe Flowing Full Velocity = Q/A	V=	1.243	fps
Energy Slope for Flowing Full = (NV)^2/(2.22R^4/3)	Se=	0.025455	ft/ft
Friction loss through the pipe = Se * L*12	dHp	30.546	inches
Energy balance = HT-dHg-dHs-dHp-V^2/64.4>= zero	**Check**	**0.00**	**inches**
Optimal Design ==> Energy Balance=0 otherwise a residual pressure exists			
E) Drain Time and Dry Time			
Drain time = Y/f	Td=	12.14	hr
Dry time= (Pore-sxHs+Pore-gxHg)/f	T-dry=	9.61	hr

Hydraulics Of Bio-Retention



SWMM orifice flow



Based on Water Volume Balance, we have:

$$An\Delta D = Q\Delta t = C_o a\sqrt{2g(D-h)}\Delta t \quad \text{where} \quad A = 0.5(Au + Ad) \text{ and } a = \pi d^2/4$$

$$\frac{nA}{(D-h)^{1/2}}\Delta D = C_o a\sqrt{2g}\Delta t \rightarrow \int_{D=D}^{D=h} n\frac{A}{(D-h)^{1/2}}d(D-h) = C_o a\sqrt{2g}\int_{t=0}^{t=T} dt$$

$$T = \frac{2nA(D-h)^{1/2}}{C_o a\sqrt{2g}} / 3600\,(hours)$$

$$C(inch^{0.5}/hr) = C_o\frac{a}{nA}\sqrt{2g}\times(12^{0.5}\times 3600) = \frac{2(D-h)^{1/2}}{T}(inch^{0.5}/hr)$$

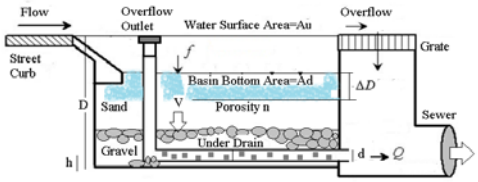
For instance, n=0.35, D= 38 inches, A= 1500 sq ft, d=2 inches, h=1 inch, Co=0.60, then the drain time T= 4.88 hr, and C=2.5

Drain Time based on Orifice Flow

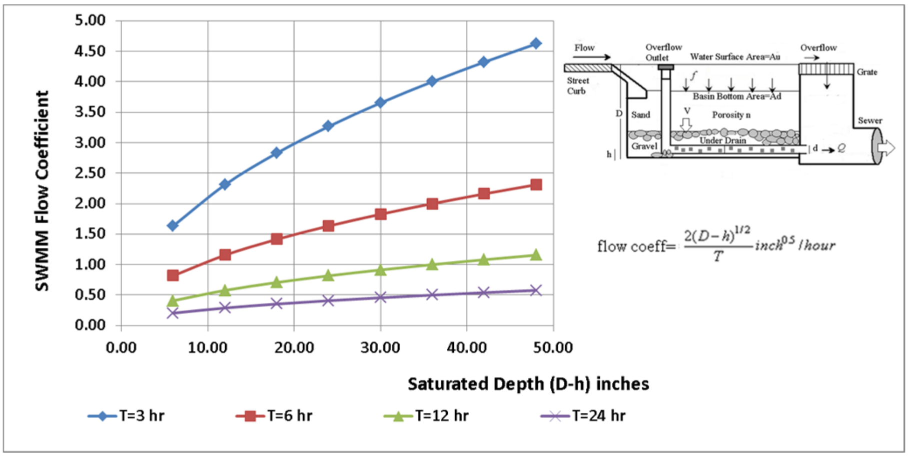
Determine the Drain Time and Drain Coeff (SWMM Method)			
Surface area of Basin	A-LID=	1500.00	sq ft
Total Depth of LID Unit	D=HT=	38.00	inch
Porosity for filtering layer or 1 for water depth	n=	0.35	
Dia of Sub-Drain	D=	2.25	inch
Orifice discharge coefficient	Co=	0.60	
Locaion of Drain Center	h=	1.50	inch
Drain Time Calculated	T=	3.83	hour
Flow Coeff based on orifice flow	C=	3.16	inch^.5/hr
Flow Coef based on drain time	C=	3.16	inch^.5/hr
Orifice Discharge=nD/T	Q=	3.48	inch/hr

$$C\,(inch^{0.5}/hr) = C_o \frac{a}{nA}\sqrt{2g} \times 12^{0.5} \times 3600 = \frac{2(D-h)^{1/2}}{T}\, inch^{0.5}/hour$$

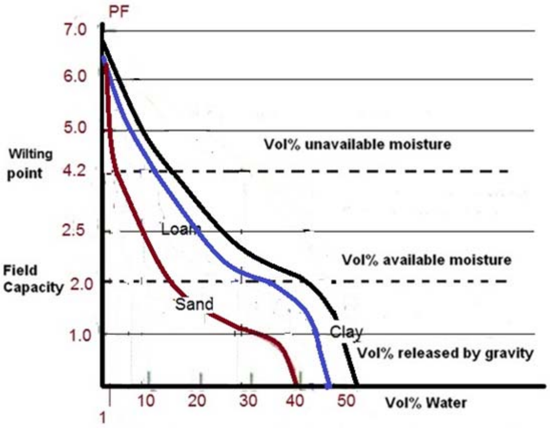
$$T = \frac{2nA(D-h)^{1/2}}{C_o a\sqrt{2g}} / 3600\ (hr)$$



SWMM Flow coefficient for Sub Drain



Field Capacity, Wilting Pt and Suction Head in Soils



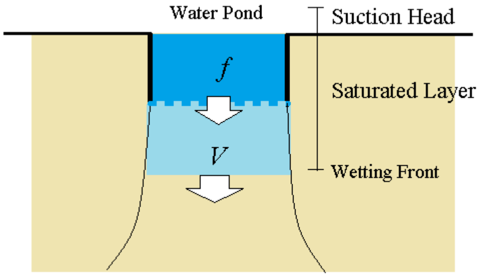
The volumetric soil moisture content remaining at field capacity is about 15 to 25% for sandy soils, 35 to 45% for loam soils, and 45 to 55% for clay soils.

The volumetric soil moisture content at the wilting point will have dropped to around 5 to 10% for sandy soils, 10 to 15% in loam soils, and 15 to 20% in clay soils.

Saturation level is between 0% at Wilting Pt and 100% at Porosity.

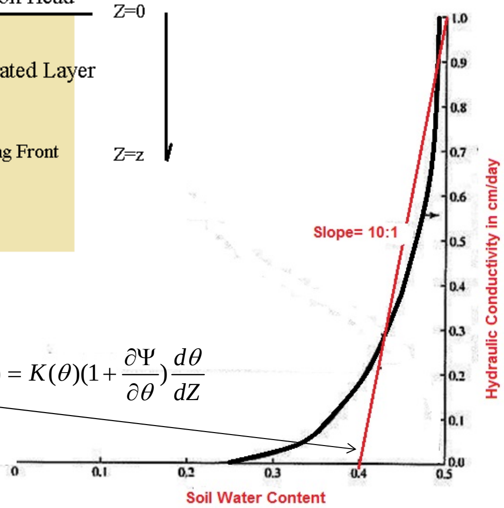
PF=log(suction head in cm); PF=*1* at field capacity, 1=log(SH); Suction Head (SH)= 10 cm

Soil Hydraulic Conductivity Curve



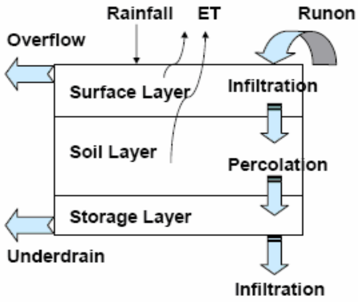
$$f(t) = f_c + (f_o - f_c)e^{-Kt}$$

$$V(\theta) = K(\theta)\, i = K(\theta)\frac{d}{dZ}(Z + \Psi) = K(\theta)(1 + \frac{\partial \Psi}{\partial \theta})\frac{d\theta}{dZ}$$



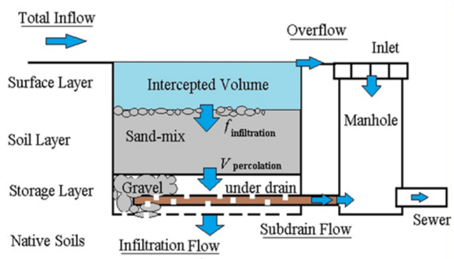
Various LID Designs – 5 Basic Elements

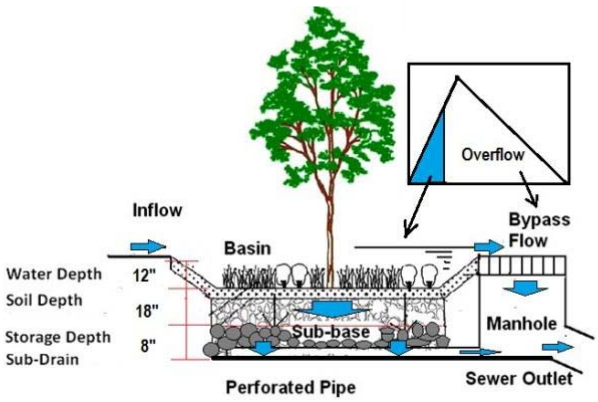
LID Type	Surface Basin	Pavement Paver	Soil Layer	Storage Gravel	Underdrain Perforated
Bio-Retention Cell	x		x	x	o
Porous Pavement	x	x		x	o
Infiltration Trench	x			x	o
Rain Barrel				x	x
Vegetative Swale	x				



Bio Retention Rain Garden

With Liner ➔no infiltration
Without Liner➔ infiltration





Flow-storage LID – SWMM Practice

Bio-retention Cells are depressions that contain vegetation grown in an engineered soil mixture placed above a gravel drainage bed. They provide storage, infiltration and evaporation of both direct rainfall and runoff captured from surrounding areas. Rain gardens, street planters, and green roofs are all variations of bio-retention cells.

Infiltration Trenches are narrow ditches filled with gravel that intercept runoff from upslope impervious areas. They provide storage volume and additional time for captured runoff to infiltrate the native soil below.

Rain Barrels (or *Cisterns*) are containers that collect roof runoff during storm events and can either release or re-use the rainwater during dry periods.

Flow-over LID – SWMM Practice

- (B-1)*Continuous Porous Pavement* -- Concrete or Asphalt
  CPP is the excavated areas filled with gravel and paved over with a porous concrete or asphalt mix. Normally all rainfall will immediately pass through the pavement into the gravel storage layer below it where it can infiltrate at natural rates into the site's native soil.

  (B-2)*Block Porous Paver* -- Modular Blocks, Tiles
  BPP consists of impervious paver blocks placed on a sand or pea gravel bed with a gravel storage layer below. Rainfall is captured in the open spaces between the blocks and conveyed to the storage zone and native soil below.

- *(B-3) Vegetative Swales* – Flat Wide Channel Bottom
  V swales are "depressed areas" with sloping sides covered with grass and other vegetation. They slow down the conveyance of collected runoff and allow it more time to infiltrate the native soil beneath it.

With and Without Liner

- Groundwater Recharge: Natural Soils

  seepage flow through the soils

  v = K i = K because i=1.0 (vertical)

  infiltration rate = ***min (f, v) = v***

  This is a slow process.

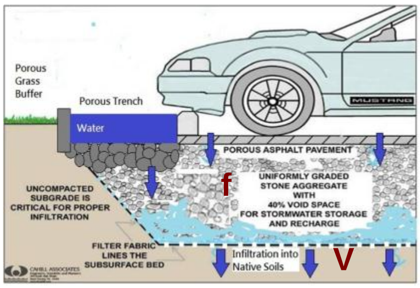
- Under-drain System : structured soils

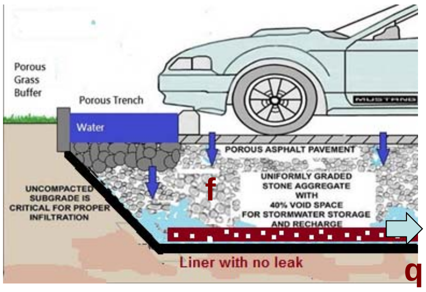
  Geotextile Liner is used to create an impermeable floor. The seepage flow is collected by a under-drain system.

  infiltration rate ***= min (f and q)***

- Clogging effect

  Infiltration trenches and porous pavement systems are subjected to a decrease in hydraulic conductivity over time due to clogging.





SCS Soil Types

Group	Meaning	Saturated Hydraulic Conductivity (in/hr)
A	Low runoff potential. Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels.	≥0.45
B	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures. E.g., shallow loess, sandy loam.	0.30 - 0.15
C	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures. E.g., clay loams, shallow sandy loam.	0.15 - 0.05
D	High runoff potential. Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay-pan or clay layer at or near the surface, and shallow soils over nearly impervious material.	0.05 - 0.00

LID Parameters

LID Type	Parameter	Default Value
Disconnection	Capture Ratio	100 %
Rain Harvesting	Cistern Size	100 gal
	Cistern Emptying Rate	50 gal/day
	Number of Cisterns	4 per 1,000 sq ft
Rain Gardens	Capture Ratio	5 %
	Ponding Depth	6 inches
	Soil Media Thickness	12 inches
	Soil Media Conductivity	10 inches/hour
Green Roofs	Soil Media Thickness	4 inches
	Soil Media Conductivity	10 inches/hour
Street Planters	Capture Ratio	6 %
	Ponding Depth	6 inches
	Soil Media Thickness	18 inches
	Soil Media Conductivity	10 inches/hour
	Gravel Bed Thickness	12 inches
Infiltration Basins	Capture Ratio	5 %
	Basin Depth	6 inches
Porous Pavement	Capture Ratio	100 %
	Pavement Thickness	4 inches
	Gravel Bed Thickness	18 inches

Property	LID Controls	Void Space
Soil Media Porosity	Rain Gardens, Green Roofs and Street Planters	45 %
Gravel Bed Void Ratio	Street Planters and Porous Pavement	75 %
Pavement Void Ratio	Porous Pavement	12 %

Surface Layer in SWMM LID

Storage Depth
When confining walls or berms are present this is the maximum depth to which water can pond above the surface of the unit before overflow occurs (in inches or mm). For LIDs that experience overland flow it is the height of any surface depression storage. For swales, it is the height of its trapezoidal cross section.

Vegetation Volume Fraction
The fraction of the volume within the storage depth filled with vegetation. This is the volume occupied by stems and leaves, not their surface area coverage. Normally this volume can be ignored, but may be as high as 0.1 to 0.2 for very dense vegetative growth.

Surface Roughness
Manning's n for overland flow over the surface of porous pavement or a vegetative swale (see this table for suggested values). Use 0 for other types of LIDs.

Surface Slope
Slope of porous pavement surface or vegetative swale (percent). Use 0 for other types of LIDs.

Swale Side Slope
Slope (run over rise) of the side walls of a vegetative swale's cross section. This value is ignored for other types of LIDs.

If either the Surface Roughness or Surface Slope values are 0 then any ponded water that exceeds the storage depth is assumed to completely overflow the LID control within a single time step.

Pavement Layer (Pavement Medium)

Thickness in inches

Typical values are 4 to 6 (100 to 150 mm).

Void Ratio

Typical values for pavements are 0.12 to 0.21.

Impervious Surface Fraction

Ratio of impervious paver material to total area for modular systems;

Permeability (in/hr or mm/hr)

Hydraulic conductivity of the fill material used in modular systems

Clogging Factor

Clogging factor= *Yclog * Pa * CR * (1 + VR) * (1 - ISF) / (T * VR)*

Yclog= number of years of service to become clogged, Pa =annual rainfall, *CR=ratio of* tributary area to paver area, *VR=* void ratio, I*SF*=impervious surface fraction, and *T* = paver thickness.

As an example, Let Yclog=5 years, Pa=14 inches/year, Cr =10, VR=0.3, ISF=0.9, T=4 inch. Clogging Factor is 5 x 14 x 10 x (1 + 0.3) / (4* 0.3)

Soil Layer (Filtering Medium)

Thickness

18 to 36 inches for rain gardens, street planters and other types of land-based bio-retention units, while 3 to 6 inches (75 to 150 mm) for green roofs.

Porosity 0.33 for sand while 0.4 to 0.5 for gravel

Field Capacity

Volume of pore water relative to total volume after the soil has been allowed to drain fully (as a fraction). Below this level, vertical drainage of water through the soil layer does not occur.

Wilting Point

Volume of pore water relative to total volume for a well dried soil where only bound water remains (as a fraction). The moisture content of the soil cannot fall below this limit.

Conductivity V=K I

Conductivity Slope

Slope of the curve of log(conductivity) versus soil moisture content (dimensionless). Typical values range from 5 for sands to 15 for silty clay.

Suction Head

The average value of soil capillary suction along the wetting front (inches or mm). This is the same parameter as used in the Green-Ampt infiltration model.

Storage Layer – Gravel medium or Barrel

Height
This is the height of a rain barrel or thickness of a gravel layer (inches or mm).
Crushed stone and gravel layers are typically 6 to 18 inches (150 to 450 mm) thick
Single family home rain barrels range in height from 24 to 36 inches (600 to 900 mm).

The following data fields do not apply to Rain Barrels.

Void Ratio
The volume of void space relative to the volume of solids in the layer.
Typical values range: 0.5 for sand, and 0.75 for gravel.
Note that porosity = void ratio / (1 + void ratio).

Infiltration Rate
The rate at which water infiltrates into the native soil below the layer (in inches/hour or mm/hour

Clogging Factor
Total volume of treated runoff it takes to completely clog the bottom of the layer divided by the void volume of the layer. Use a value of 0 to ignore clogging.

Under Drain Layer

Drain Coefficient and Drain Exponent

If the layer does not have an underdrain then set C to 0.
Coefficient *C* and exponent *n* that determines the rate of flow through the underdrain as a function of height of stored water above the drain height. The following equation is used to compute this flow rate (per unit area of the LID unit):

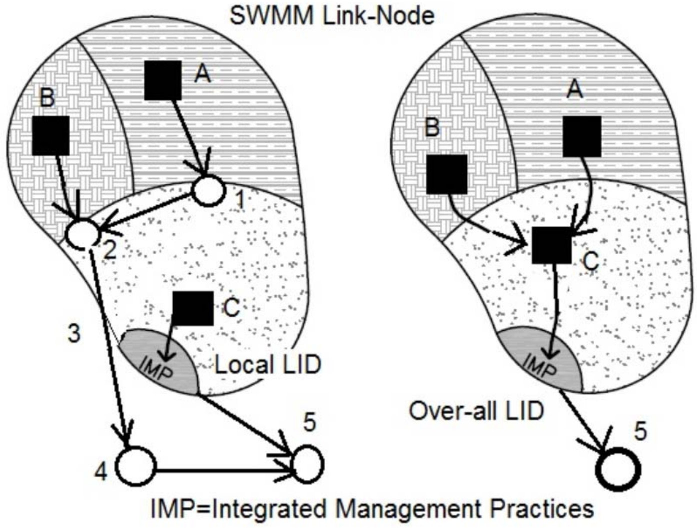
$q = C(h-Hd)^n$

q= outflow (in/hr or mm/hr),
h=height of stored water (inches or mm),
Hd =drain height. n= 0.5 (making the drain act like an orifice).
For n = 0.5, C = 2D$^{1/2}$*/T. In which T = drain time, D = depth of stored water*

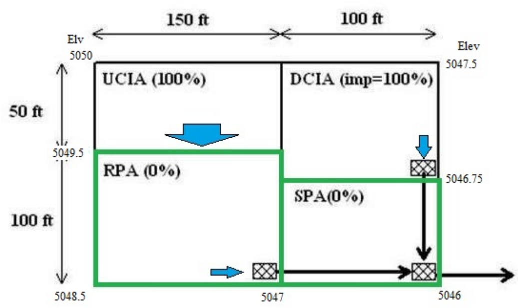
Drain Offset Height
Height of any underdrain piping above the bottom of a storage layer or rain barrel (inches or mm).

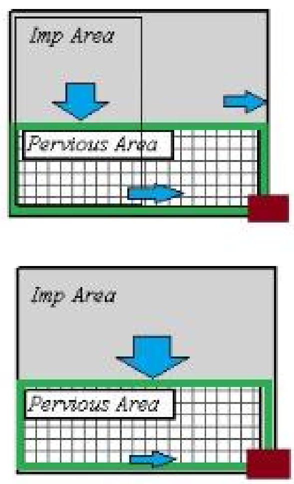
Drain Delay (for Rain Barrels only)
The number of dry weather hours that must elapse before the drain line in a rain barrel is opened (the line is assumed to be closed once rainfall begins). This parameter is ignored for other types of LIDs.

LID is flow-path dependent
Local versus Over-all Treatment

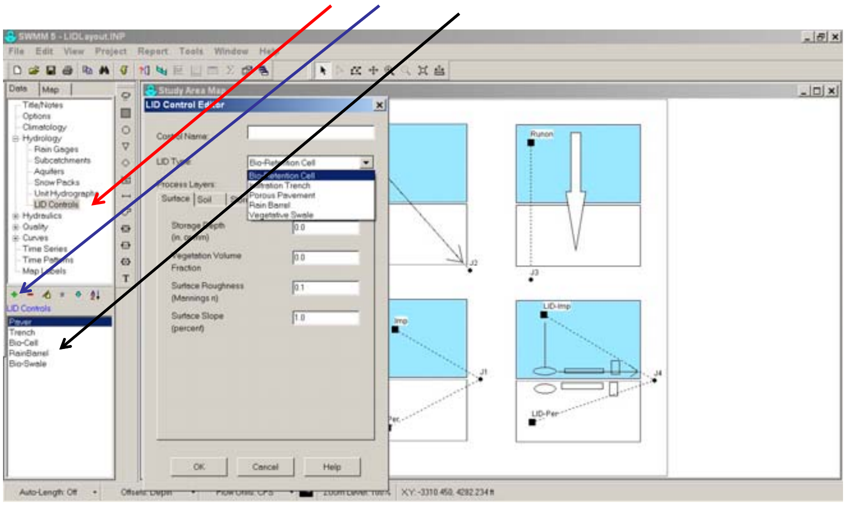


LID is a cascading flow system
% of Run-on Flow Interception



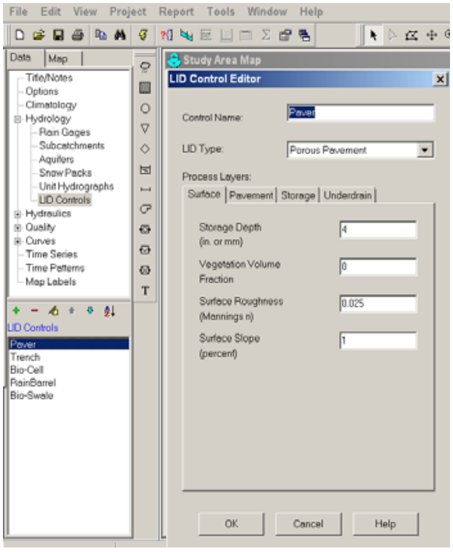


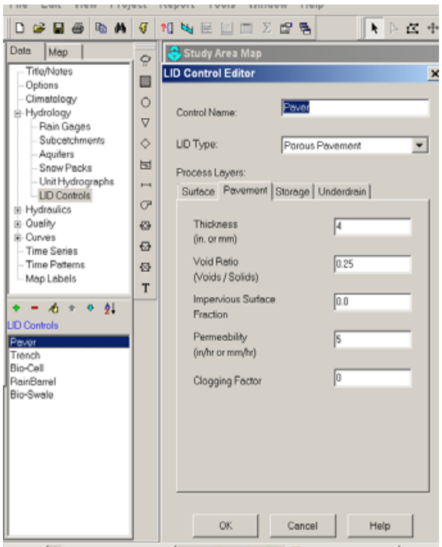
Create a Menu of LID Facilities



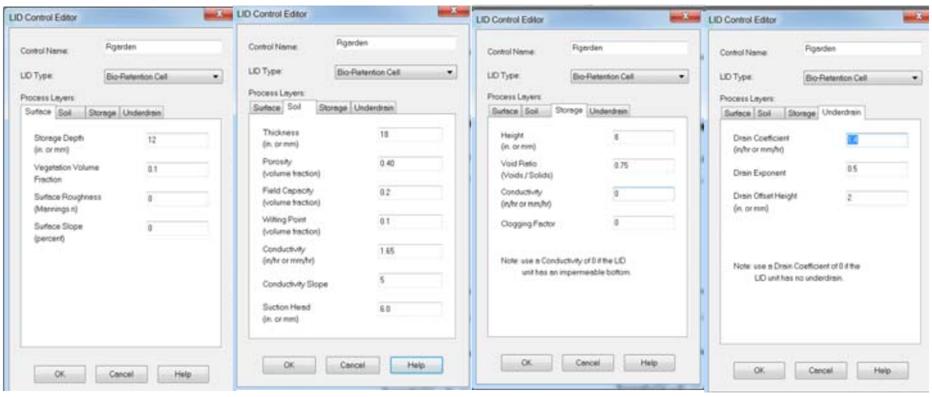
Use + and – to add or to remove a LID

LID Input Parameters



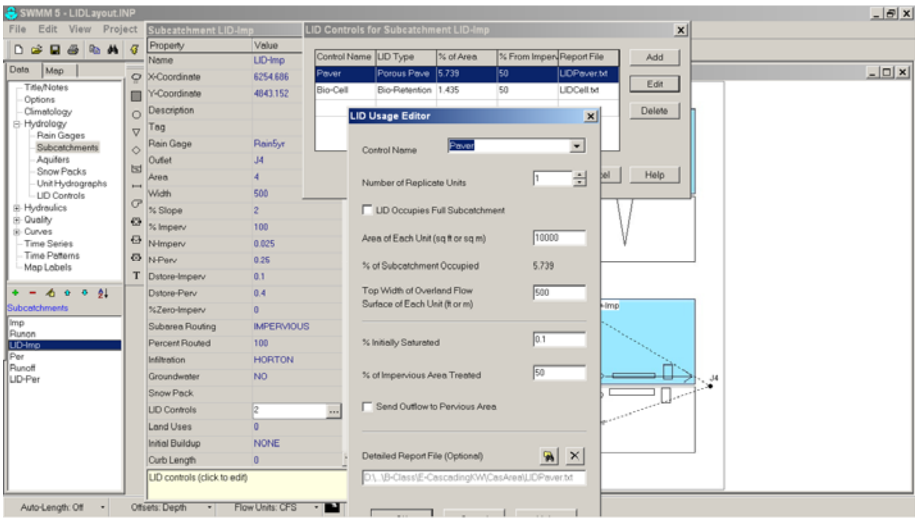


Define Standard LID Dimension
Example: Bio-retention

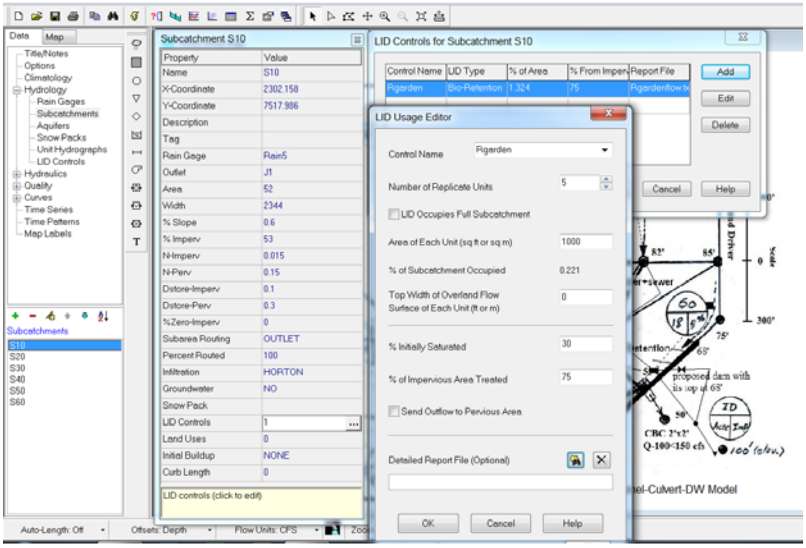


Do not blindly accept the default values in SWMM LID
Wilting point = 1% moisture content (saturation level =0%)
Conductivity slope = 5 for sand and 15 for silt
Suction head = fct (soil water content) = Log (PF value)
Porosity = Void Volume/Total Soil Volume (saturation level =100%)
Void ratio= void/solid volume ratio, 0.12 for paver, 0.50 for sand, 0.75 for gravel.
Storage conductivity>0 =➔ leaking into groundwater table
For sub-drain: n = 0.5, C = 2D$^{1/2}$/T in which D= diameter and T= drain time or C=0 if no sub drain

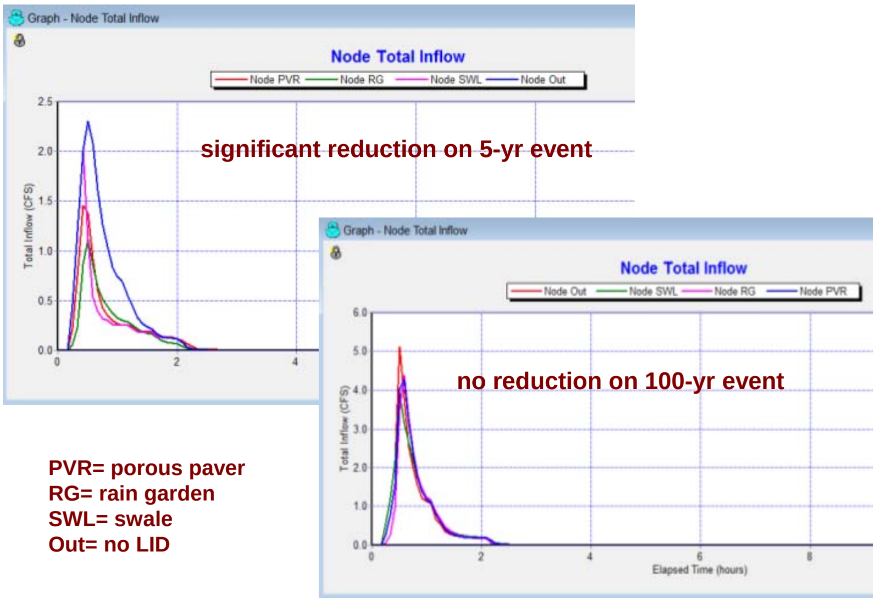
Add LID Controls into a Subarea



Add LIDs to Sub-catchment
Example: Bio-retention



Diminishing effect of LID on Q reduction



PVR= porous paver
RG= rain garden
SWL= swale
Out= no LID

Q and A

James.Guo@UCDenver.edu
WWW.UCDENVER.EDU/~Jguo
WWW.UDFCD.ORG
WWW.URBANWATERSHEDS.ORG

FOR MORE INFORMATION

James.Guo@UCDenver.edu
WWW.UCDENVER.EDU/~Jguo -- Website
WWW.UDFCD.ORG -- Free Software
WWW.URBANWATERSHEDS.ORG – Training Classes

My kind of Confusing Porous Pavers