Stormwater LID Practices

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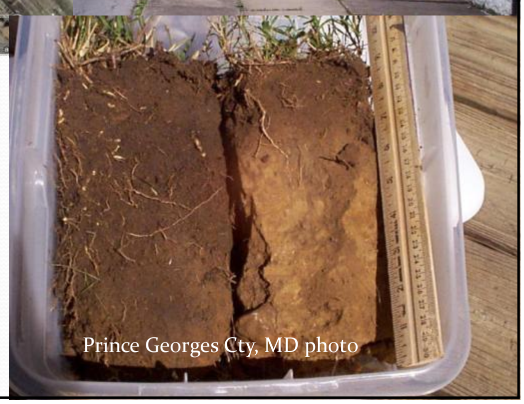
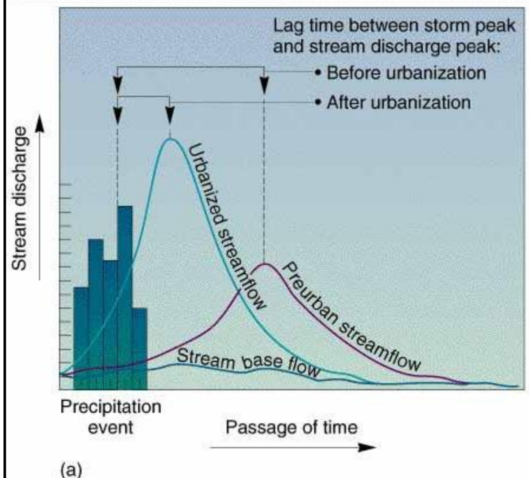
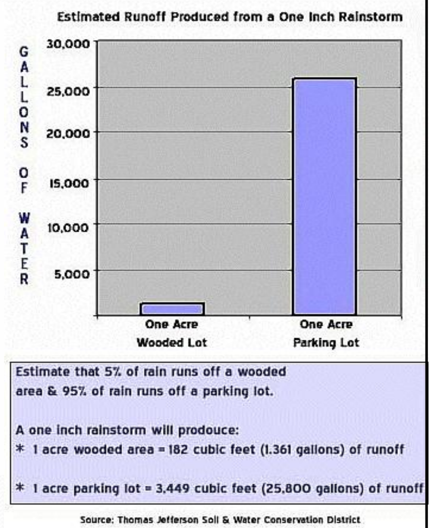
Prior development decisions have led to directly connected impervious areas and "pervious" areas with heavily-compacted soils.

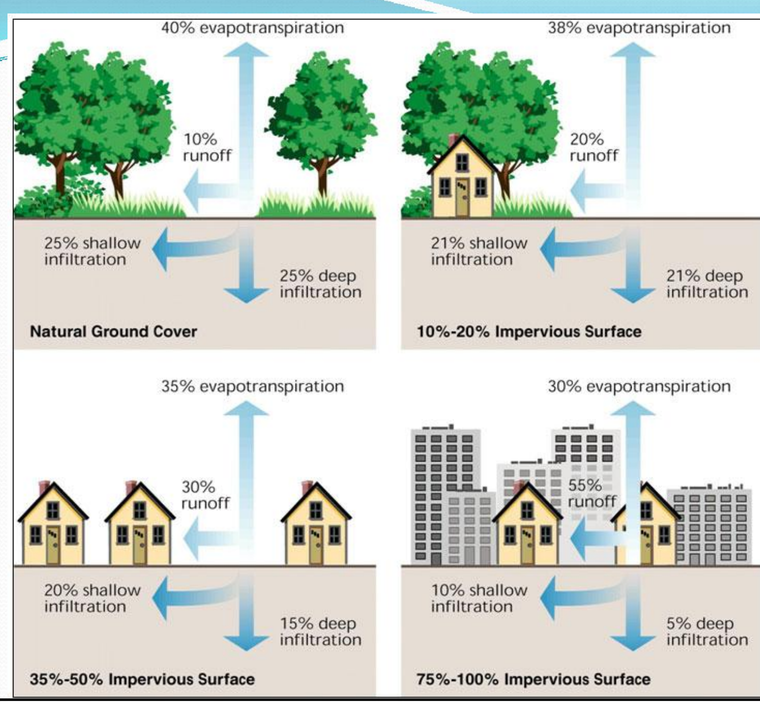


Prince Georges Cty, MD photo

Urbanization often shortens watershed response times and increases flow volumes and rates…







Goal: Replicate Natural Hydrology

- Increase infiltration
  - Replenish streamflows
  - Recharge groundwater
- Increase evapotranspiration
  - Aesthetics
  - Urban heat island effect

Techniques for LID

Technique	Groundwater Recharge	Rate (R) or Volume (V) Control	Water Quality
Pervious Pavement	Type of lining?	R: Yes V: lining?	Yes(?)
Infiltration Basin	Type of lining?	R: Yes V: lining?	Yes
Infiltration Bed	Type of lining?	R: Yes V: lining?	Yes
Infiltration Trench	Type of lining?	R: Yes V: lining?	Yes
Rain Garden / Bioretention	Type of lining?	R: Yes V: lining?	Yes
Dry Well / Seepage Pit	Type of lining?	R: Yes V: lining?	Yes
Constructed Filter	Type of lining?	R: Yes V: lining?	Yes
Vegetated Swale	Type of lining?	R: Yes V: lining?	Yes
Vegetated Filter Strip	Type of lining?	R: Yes V: lining?	Yes
Infiltration Berm	Type of lining?	R: Yes V: lining?	Yes
Vegetated Roof	No	R: Yes? V: Yes	Yes?

Techniques for LID

Technique	Groundwater Recharge	Rate (R) or Volume (V) Control	Water Quality
Capture and Re-use	??	Yes	Yes
Constructed Wetlands	Yes	Yes	Yes
Wet Pond/Retention Basin	No	R: Yes V: No	Yes (?)
Dry Extended Detention Basin	No	R: Yes V: No	No
Water Quality Filters & Hydrodynamic Devices	No	R: Yes? V: No	Yes (?)
Riparian Buffer Restoration	No	Yes	Yes
Landscape Restoration / Reforestation	Yes	Yes	Yes
Soil Amendment/ Restoration	Yes	Yes	Yes (?)
Level spreader	No	R: Yes V: No	No

Designing to Incorporate LID

Site Design Techniques (PA Manual: Non-Structural Practices)

- "Non-Structural BMP deployment is not a singular, prescriptive design standard but a combination of practices that can result in a variety of environmental and financial benefits. Reliance on Non-Structural BMPs encourages the treatment, infiltration, evaporation, and transpiration of precipitation close to where it falls while helping to maintain a more natural and functional landscape."
  - NS BMP 5.4.1 - Protect Sensitive / Special Value
  - NS BMP 5.4.2 - Protect / Conserve / Enhance Riparian Buffers
  - NS BMP 5.4.3 - Protect / Utilize Natural Drainage Features
  - NS BMP 5.5.4 - Cluster Uses at Each Site
  - NS BMP 5.6.1 - Minimize Total Disturbed Area
  - NS BMP 5.6.2 - Minimize Soil Compaction
  - NS BMP 5.6.3 - Re-Vegetate / Re-Forest Disturbed Areas (Native Species)
  - NS BMP 5.9.1 - Street Sweeping / Vacuuming

Designing the Next Generation of Stormwater Practices

Maintain Time of Concentration

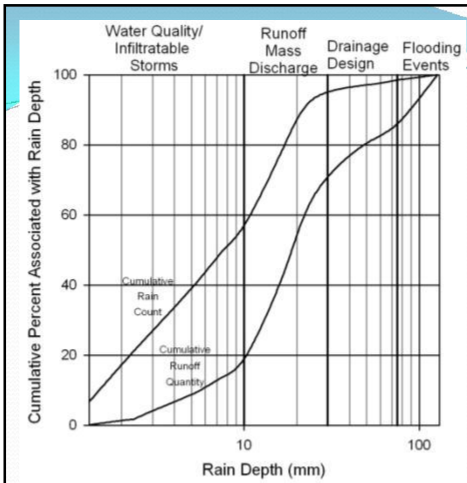
Techniques:

- Open drainage
- Use green space
- Flatten slopes
- Disperse drainage
- Lengthen flow paths
- Save headwater areas
- Vegetative swales
- Maintain natural flow paths
- Increase distance from streams
- Maximize sheet flow

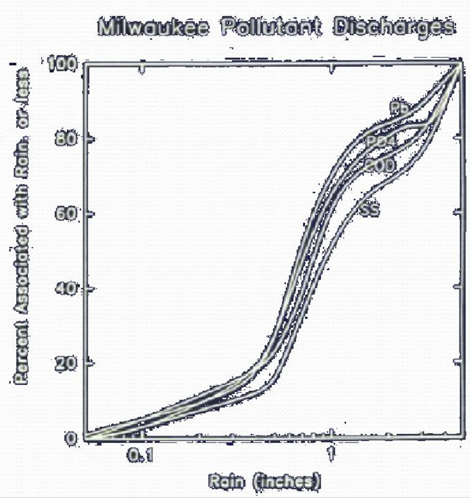
Maintaining pre-development time of concentration essential!

Specific Stormwater Management Practices

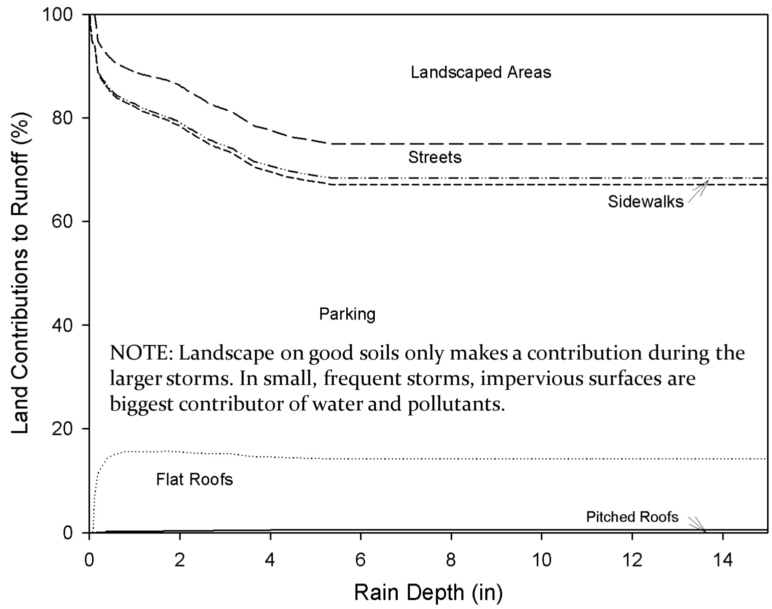
With references to PA Stormwater BMP Manual design criteria



What Can Our Storm Distributions Tell Us about Planning?
SCS Type II Rainfall Example



Central and Western PA are in the SCS Type II Rainfall Design Storm area.



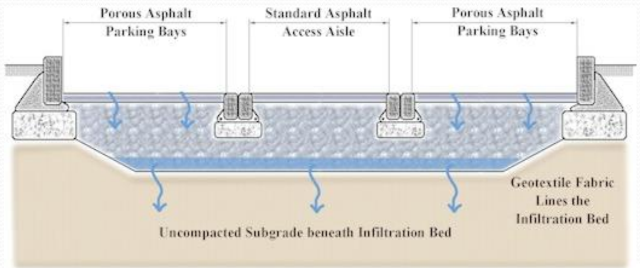
Technique: Permeable Pavement

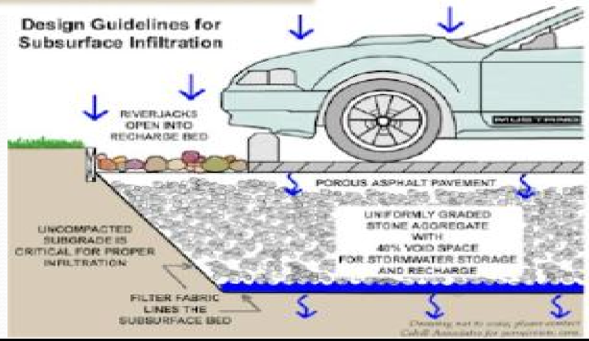
- Allows water to pass through and infiltrate into the ground
  - Austin, Texas parking lot initial infiltration 1,765 in/hr
- Benefits: Control of TSS and particulate-associated pollutants
- Concerns: Permeable pavement may not work as well in areas with extreme rainfall amounts, less permeable soils, or dissolved pollutants.
- Many of these operate as underground detention storage.
- Permeable and no liners allow for infiltration to either shallow or deep groundwaters.
- Variety of materials available for permeable pavers.

Permeable Pavement

Porous Paver Blocks

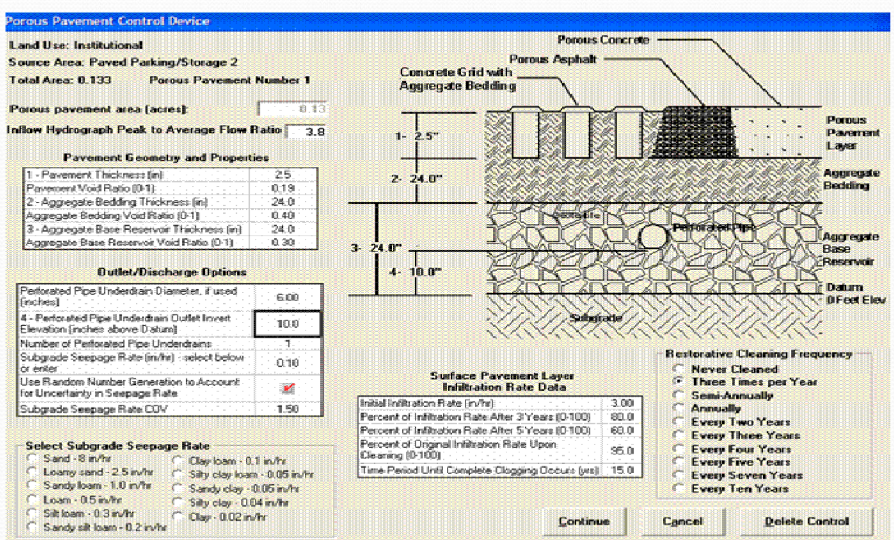
Technique: Porous Pavement Design





PADEP, 2006

Technique: Porous Pavement Design



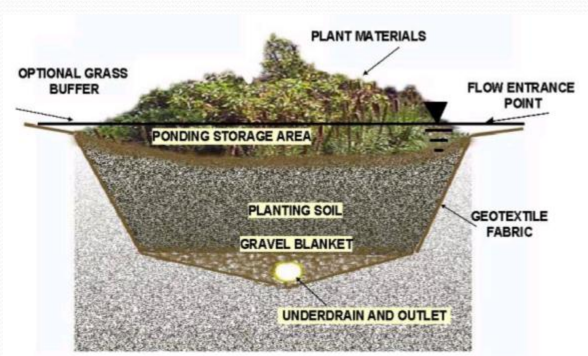
Technique: Permeable Pavement Design Equations

Volume Reduction Calculations

- Volume = Depth* (ft) x Area (sf) x Void Space
  - *Depth is the depth of the water stored during a storm event, depending on the drainage area and conveyance to the bed.
- Infiltration Volume = Bed Bottom Area (sf) x Infiltration design rate (in/hr) x Infiltration period* (hr) x (1/12)
  - *Infiltration Period is the time when bed is receiving runoff and capable of infiltrating at the design rate.
- No time used in the calculations can exceed 72 hours. (maximum draindown time)

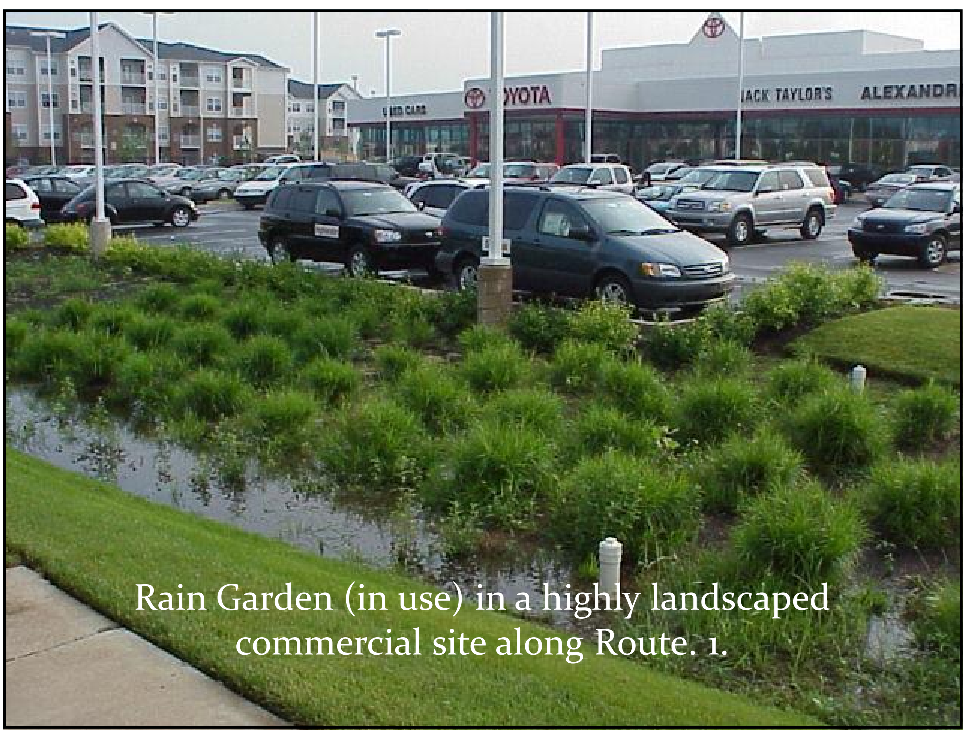
Technique: Bioretention Cells/Rain Gardens

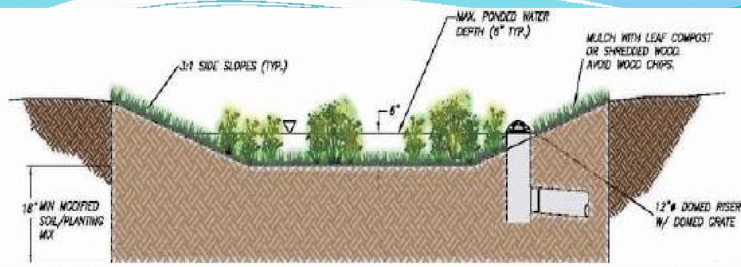
- Layers of sand/soil mixture, rock & vegetation to create area for stormwater to collect and filter through the soil. Infiltration depends on lining (if applicable).
- Bioretention cells control quantity as well as quality of the stormwater

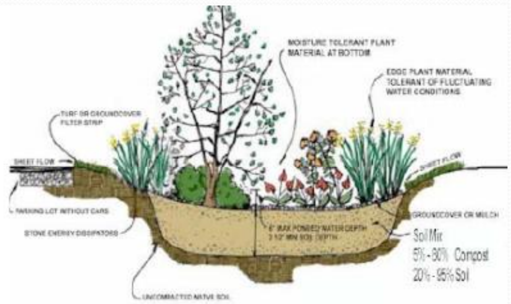



Rain Garden Designed for Complete Infiltration of Roof and Parking Lot Runoff


Installation of Rain Garden/Bioretention Facility in Parking Lot


Rain Garden (in use) in a highly landscaped
commercial site along Route. 1.





PADEP, 2006

Technique: Bioretention Design Guidance

Sizing criteria

- **Surface area** … should generally not exceed a maximum loading ratio of 5:1 (impervious drainage area to infiltration area)
- **Surface Side slopes** … maximum 3:1 side slopes are recommended, however where space is limited, 2:1 side slopes may be acceptable.
- **Surface Ponding depth** should not exceed 6 inches in most cases and should empty within 72 hours.
- **Planting soil depth** should generally be at least 18" where only herbaceous plant species will be utilized.
- **Planting Soil** should be a loam soil capable of supporting a healthy vegetative cover. … A typical organic amended soil is combined with 20-30% organic material (compost), and 70-80% soil base (preferably topsoil).
- **Volume Storage Soils** should also have a pH of between 5.5 and 6.5, a clay content less than 10% , be free of toxic substances and unwanted plant material, and have a 5 –10% organic matter content.

Technique: Bioretention Design Guidance

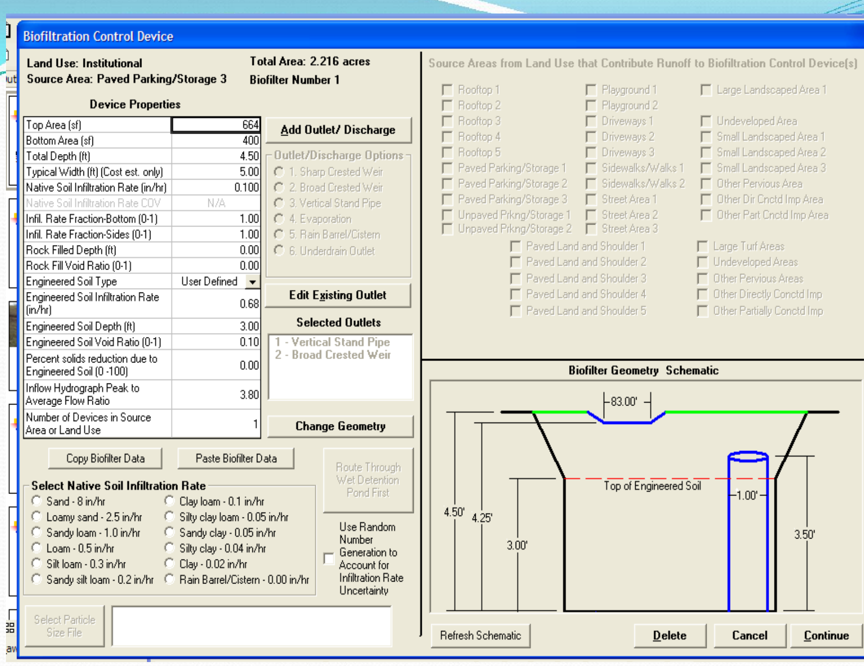
Volume Reduction Calculations

The storage volume of a Bioretention area is defined as the sum total of (1) and the smaller of (2a) or (2b) below. The surface storage volume should account for at least 50% of the total storage.

(1) Surface Storage Volume (CF) = Bed Area (ft2) x Average Design Water Depth

(2a) Infiltration Volume = Bed Bottom area (sq ft) x infiltration design rate (in/hr) x infiltration period (hr) x 1/12.

(2b) Volume = Bed Bottom area (sq ft) x soil mix bed depth x void space.

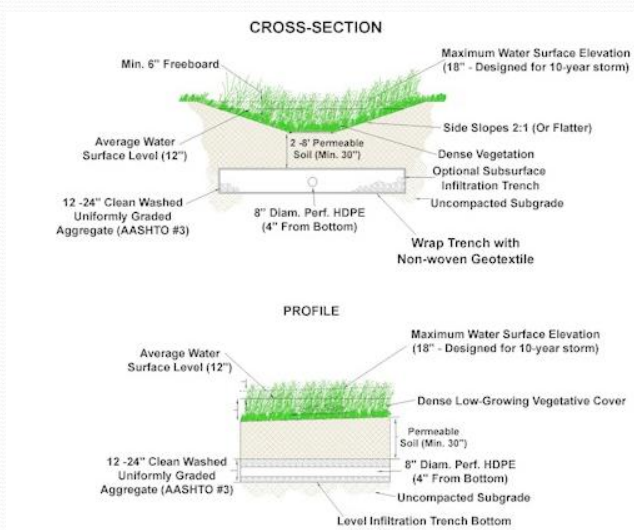


Technique: Grass Swales and Filter Strips

- Grass Swales:
  - Replaces curb & gutter systems
  - Uses grass & other vegetation to redirect high volume flows
  - Reduces runoff velocity
  - May allow runoff to infiltrate into soil
- Filter Strips
  - Typically placed in parking lots or other large impervious surfaces
  - Collects water for infiltration or for treatment prior to discharge to the traditional storm drainage system.
  - Can direct the water to bio-retention areas

Grass Swales Designed to Infiltrate Large Fractions of Runoff

Technique: Vegetated Swale Design (per DEP 2006)



Technique: Design Calculations for Grass Swale

- Temporarily store and infiltrate the 1-inch storm event
- Provide conveyance for up to the 10-year storm with freeboard and no erosion of the channel.
- Maximum ponding depth of 18 inches at the end point of the channel, with a 12-inch average maintained throughout.
- Six inches of freeboard is recommended for the 10-year storm.
- Residence times between 5 and 9 minutes are acceptable for swales without check-dams.
- Maximum ponding time is 48 hours, though 24 hours is more desirable (minimum of 30 minutes).
- Swale vegetation should not be submerged during design storm or smaller.
- Longitudinal slopes between 1% and 3%. (for steeper slopes, check dams or TRM's used to reduce energy gradient).

Technique: Design Calculations for Grass Swale

- Check dams also enhance infiltration capacity, decrease runoff volume, rate, and velocity, and promote additional settling of pollutants. Check-dams create a series of small, temporary pools along the length of the swale.
- Check-dams shall be constructed to a height of 6 to 12 in and be regularly spaced.
- Siting should aesthetically fit the swale into the landscape. Sharp bends in swales should be avoided.
- Where possible, construct swales in areas of uncompacted cut. Avoid constructing side slopes in fill material.
- Soil Testing is required when infiltration is planned (see Appendix C).
- Swales are typically most effective, when treating an area of 1 to 2 acres although vegetated swales can be used to treat and convey runoff from an area of 5 to 10 acres in size.
- Runoff can be directed either as concentrated flows or as lateral sheet flow drainage.

Technique: Design Calculations for Grass Swale

- Swale soils should be well-drained. If the infiltration capacity is compromised during construction, the first several feet should be removed and replaced with a blend of topsoil and sand.
- Swales are most efficient when their cross-sections are parabolic or trapezoidal in nature. Swale side slopes are best within a range of 3:1 to 5:1 and should not be greater than 2:1 .
- Bottom widths typically range from 2 to 8 feet. Wider channels require berms or walls to prohibit braiding or uncontrolled sub-channel formation. The maximum bottom width to depth ratio for a trapezoidal swale should be 12:1.
- Ideal swale vegetation should consist of a dense and diverse selection of close-growing, water-resistant plants whose growing season preferably corresponds to the wet season. Swale vegetation must also be salt tolerant, if winter road maintenance activities are expected to contribute salt/chlorides.

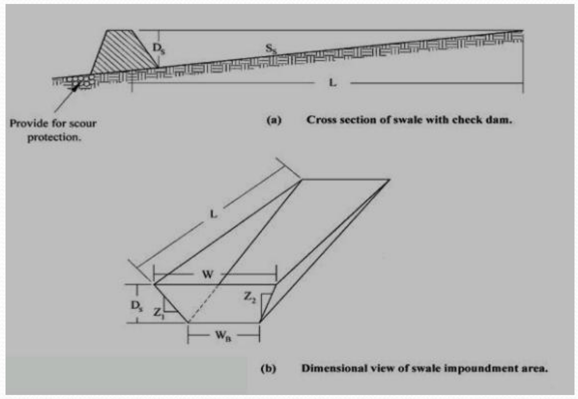
Technique: Design Calculations for Grass Swale

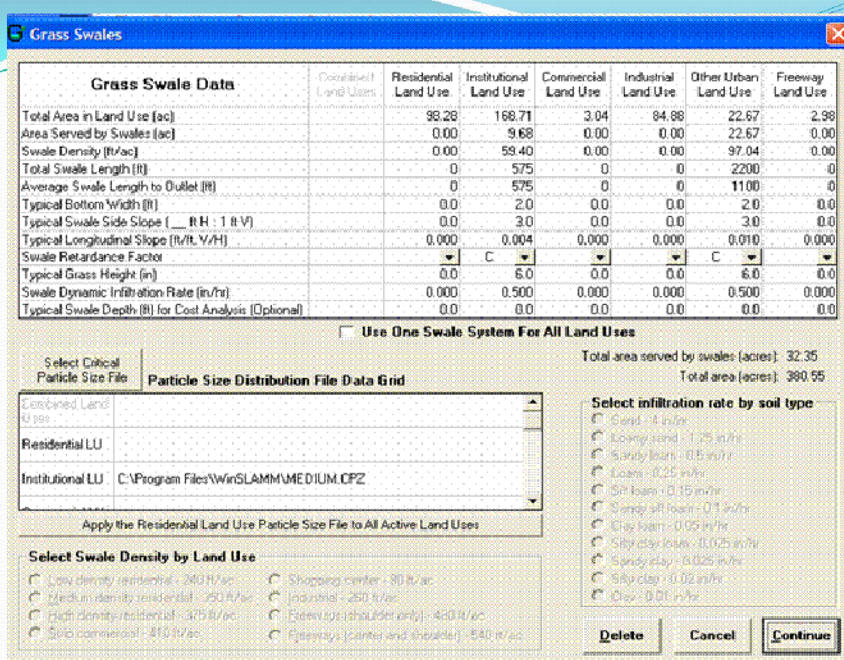
- Check the temporary and permanent stability of the swale using the standards outlined in the Pennsylvania Erosion and Sediment Pollution Control Program Manual.
- Swales should convey either 2.75 cfs/acre or the calculated peak discharge from a 10-year storm event.
- The permissible velocity design method may be used for design of channel linings for bed slopes <0.10 ft/ft; use of the maximum permissible shear stress is acceptable for all bed slopes.
- Flow capacity, velocity, and design depth in swales are generally calculated by Manning's equation.
- The post-vegetation establishment capacity of the swale should also be confirmed.
- Swales should discharge to another structural BMP, existing stormwater infrastructure, or a stable outfall.

Technique: Design Calculations for Grass Swale

- **Volume Reduction Calculations**
- Volume retained behind each check-dam :

  Storage Volume = 0.5 x Length of Swale Impoundment Area/Check Dam x Check Dam Depth x (Top Width of Check Dam + Bottom Width of Check Dam) / 2





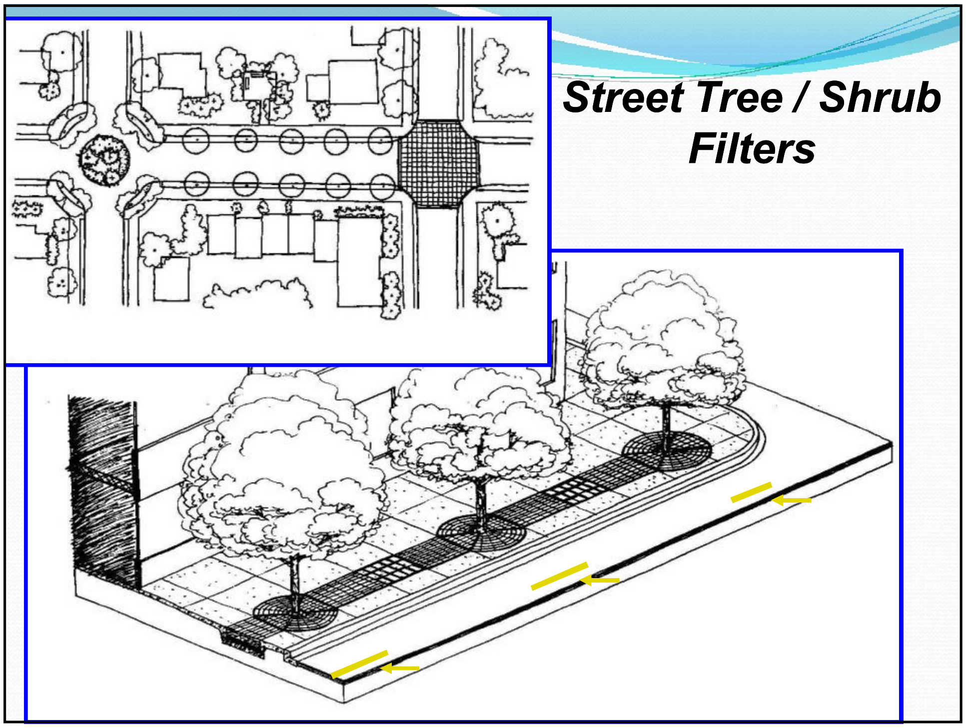
Grass Swale Data	Combined Land Uses	Residential Land Use	Institutional Land Use	Commercial Land Use	Industrial Land Use	Other Urban Land Use	Freeway Land Use
Total Area in Land Use (ac)		98.28	168.71	3.04	84.88	22.67	2.98
Area Served by Swales (ac)		0.00	9.68	0.00	0.00	22.67	0.00
Swale Density (ft/ac)		0.00	59.40	0.00	0.00	97.04	0.00
Total Swale Length (ft)		0	575	0	0	2200	0
Average Swale Length to Outlet (ft)		0	575	0	0	1100	0
Typical Bottom Width (ft)		0.0	2.0	0.0	0.0	2.0	0.0
Typical Swale Side Slope (__ ft H : 1 ft V)		0.0	3.0	0.0	0.0	3.0	0.0
Typical Longitudinal Slope (ft/ft, V/H)		0.000	0.004	0.000	0.000	0.010	0.000
Swale Retardance Factor			C			C	
Typical Grass Height (in)		0.0	6.0	0.0	0.0	6.0	0.0
Swale Dynamic Infiltration Rate (in/hr)		0.000	0.500	0.000	0.000	0.500	0.000
Typical Swale Depth (ft) for Cost Analysis (Optional)		0.0	0.0	0.0	0.0	0.0	0.0

Rainwater Harvesting

- Reduces runoff into drainage system.
- Can replace potable water used for landscape irrigation.

Variations on a Theme

With references to PA Stormwater BMP Manual design criteria


Street Tree / Shrub
Filters


Tree and Shrub
Box
Guide Water to Tree/Shrub Box

Modernizing Development Practices

Narrow streets with angled parking draining to bioretention

Green = green roof

Blue = bioretention

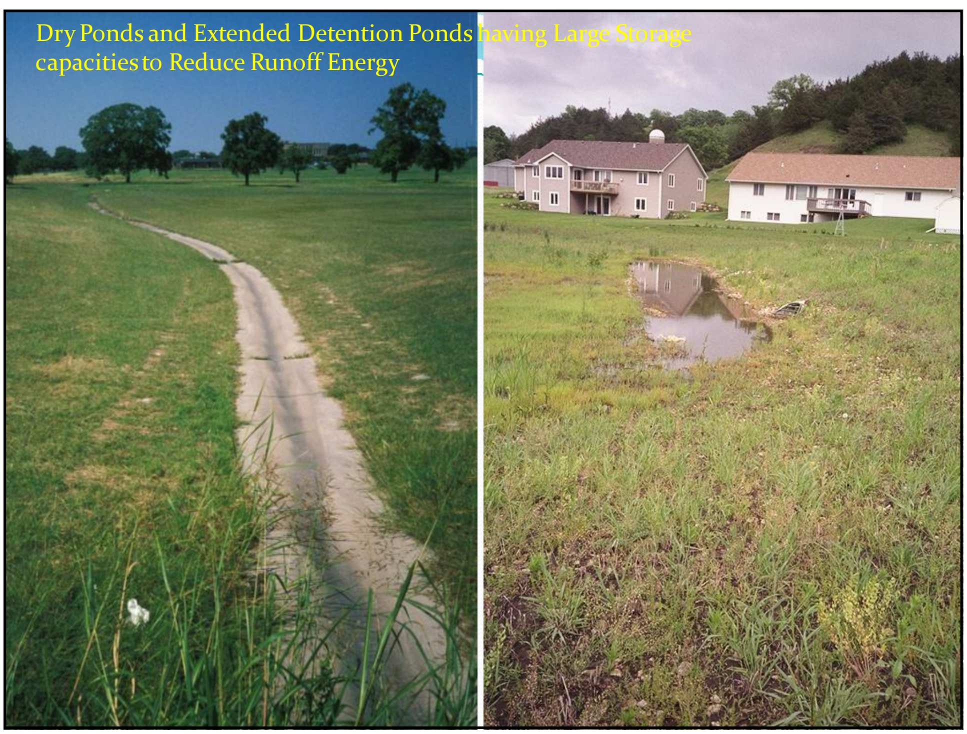
Red = rejuvenated detention basin/ballfields

Orange = pervious pavement

Conventional Practices Still Have a Place: Wet/Dry Detention/Retention Ponds

- Traditionally used to mitigate peak flows to pre-development limits.
  - Problem: Retain significant quantities of water that are released at the highest pre-development rate for a longer period of time.
    - Subjects receiving water to maximum energy for a longer period of time.
- Still, integral part of stormwater management system.
  - Can be used as an infiltration basin.
  - May be needed to mitigate flooding and reduce peak flow rates in large storms.
    - But definitely can be smaller!


Wet Detention Ponds to Treat Large Flows


Dry Ponds and Extended Detention Ponds having Large Storage capacities to Reduce Runoff Energy

What About Water Quality and TMDLs?

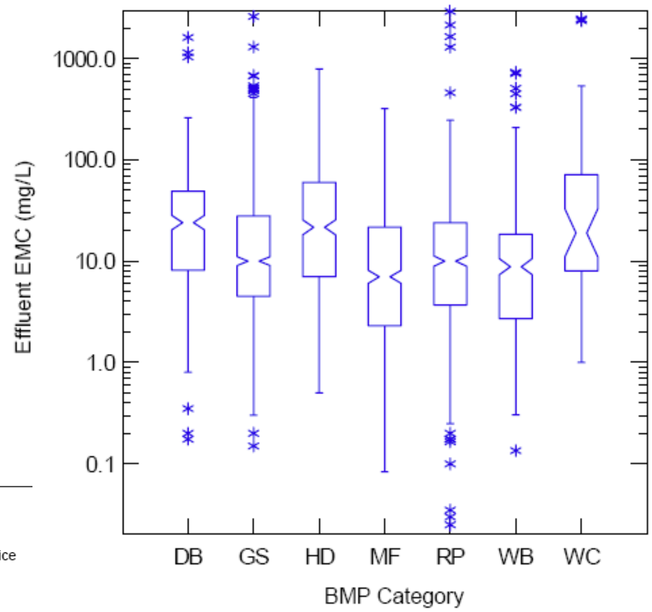
The manual provides estimated percent removals for each practice, but

(1) Percent removals are not applicable in all situations
(2) Challenge of pollutants not listed in percent removals

International Stormwater BMP Database (www.bmpdatabase.org)

- These summaries focus on two separate data analyses:
- A data set composed of each BMP study's average effluent event mean concentrations (EMCs) over the entire respective monitoring period, grouped by BMP category.
- A data set comprised of all of the individual effluent EMCs, grouped by BMP category.
- An assessment was also made of the difference between the median effluent values and the corresponding influent values for both data sets.

Total Suspended Solids (TSS)

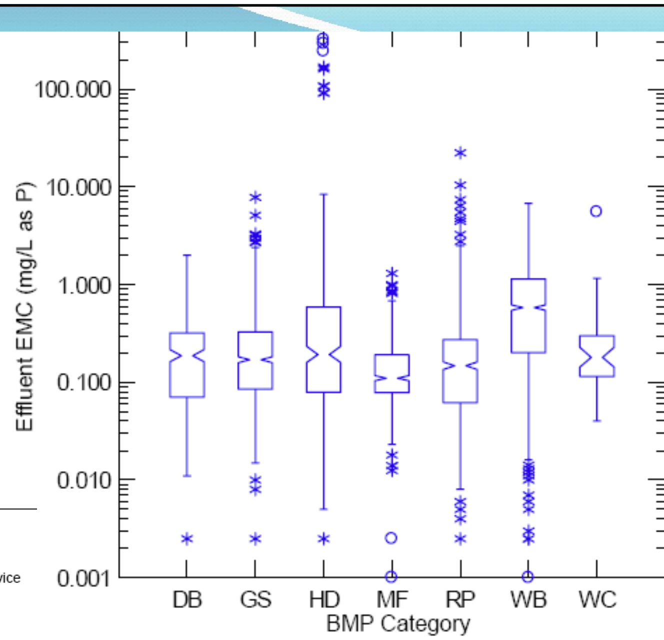


BMP Category

DB	Detention Basin
GS	Biofilter
HD	Hydrodynamic Device
MF	Media Filter
RP	Retention Pond
WB	Wetland Basin
WC	Wetland Channel

Figure 2. Individual effluent TSS EMCs by BMP category

Total Phosphorus (TP)



BMP Category

DB	Detention Basin
GS	Biofilter
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Figure 2. Individual effluent TP EMCs by BMP category

Total Nitrogen (TN)

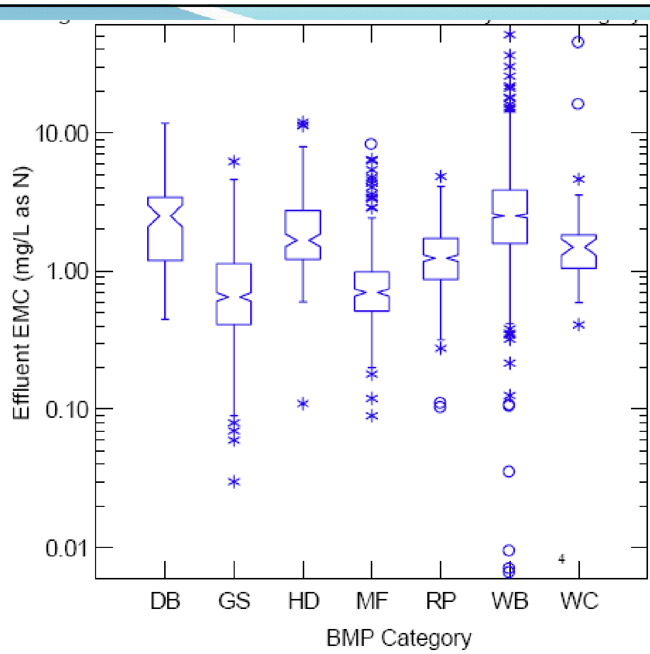


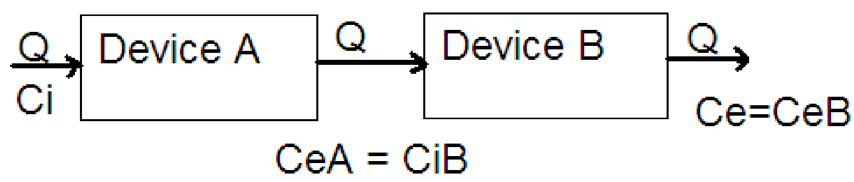
Figure 2. Individual effluent TN EMCs by BMP category

BMP Category	
DB	Detention Basin
GS	Biofilter
HD	Hydrodynamic Device
MF	Media Filter
RP	Retention Pond
WB	Wetland Basin
WC	Wetland Channel

Example: Potential Treatment Options to Meet a Permit Limit of 20 mg/L TSS, 0.1 mg/L TP, and 1 mg/L TN

	TSS	TP	TN
Detention Basin (DB)	40^{th} percentile	30^{th} percentile	20^{th} percentile
Biofilter (GS)	65^{th} percentile	30^{th} percentile	75^{th} percentile
Hydrodynamic Device (HD)	40^{th} percentile	35^{th} percentile	20^{th} percentile
Media Filter (MF)	75^{th} percentile	40^{th} percentile	80^{th} percentile
Retention Pond (RP)	75^{th} percentile	35^{th} percentile	40^{th} percentile
Wetland Basin (WB)	80^{th} percentile	15^{th} percentile	20^{th} percentile

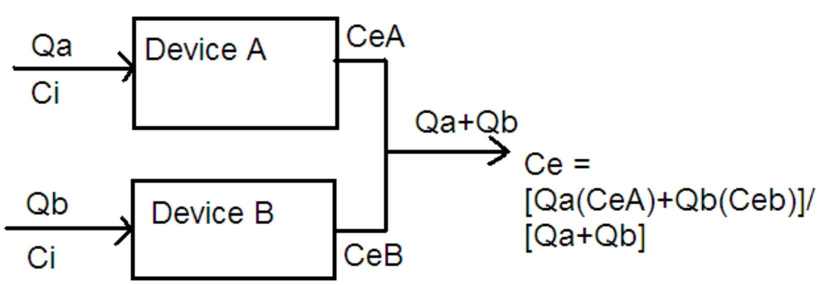
Calculating Treatment Effectiveness: Devices in Series



Å Final Effluent Quality Controlled by Effluent of Device B.

Å Device A generally has no impact on final water quality, unless substantial reductions in pollutant concentration needed to prevent damage to Device B (sediment forebay, for example)

Calculating Treatment Effectiveness: Devices in Parallel



Å Final Effluent Quality Controlled by Weighted Average of Performance of Two Devices (weighted by flow rates through each device).

Å Suggested applications would be providing treatment to some portion of flow to reduce concentrations without providing treatment to entire flow stream.

Appropriate Combinations of Controls

- No single control is adequate for all problems!
- Only infiltration reduces water flows substantially, along with soluble and particulate pollutants. Evapotranspiration devices effective for small storms.
  - Infiltration only applicable in conditions having minimal groundwater contamination potential.
- Wet detention ponds reduce particulate pollutants and may help control dry weather flows.
  - They do not consistently reduce concentrations of soluble pollutants, nor do they generally solve regional flooding problems (extended release and multiple pond releases).
- A combination of practices is usually needed, usually as a treatment train (although the practices may be separated by distance on a site).
- Order of cost (least to most) and ease: Solids control → particulate pollutant control → dissolved pollutant control.