Low Impact Development

Presented by
Fort Carson's Stormwater Program
and AECOM

[redacted]

Agenda

- EISA 07 – Who, What and Why
- Limitations of Conventional Stormwater Management (flood control vs. LID?) (bioretention vs. detention)
- LEED credits
- Colorado and Western Water Rights
- Exemptions
- Video - Philadelphia Story
- Break
- Berm
- Curb Cuts and Other Disconnects
- Permeable Pavers
- Geo Textile Grids
- Ditches and Check Dams

Agenda (Continued)

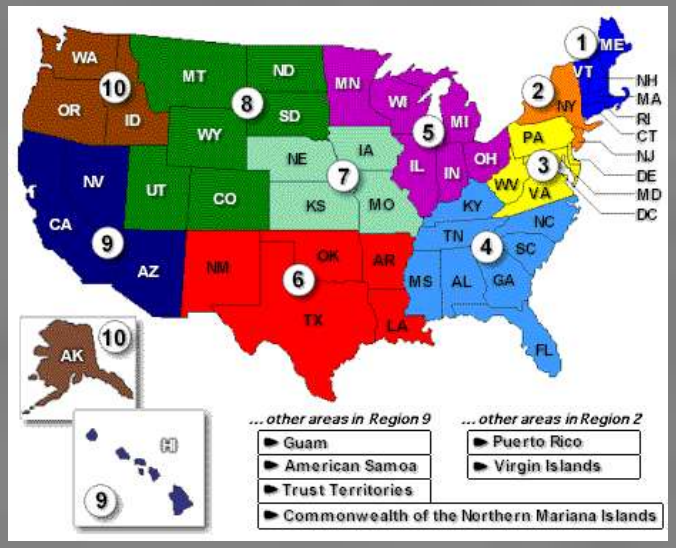
- Bio Swale
- Rain Garden
- Soil Augmentation
- Wetlands and Green Roofs
- Disconnect impervious Areas
- Tree Box
- Planters
- Video -
- Vegetation
- Design Guide and Criteria, Plant Species
- Places to Find Design Support
- Open Discussion

Andy Boudreau AECOM

- Introduction to LID
- EISA 07 – Who, What and Why
- Limitations of Conventional Stormwater Management (flood control vs. LID?) (bioretention vs. detention)
- LEED credits
- Colorado and Western Water Rights
- Exemptions

Background to EISA07

- **Clean Water Act**
  - **Municipal Separate Storm Sewer System (MS4) permits**
  - **Multi-Sector General Permits (MSGP) for stormwater discharges associated with industrial activity**
  - **Construction General Permits (CGP)**
  - **NPDES permits (point sources)**
  - **303d list (impaired waters; TMDLs)**
  - **404 Wetlands**
  - **State or Tribal regulations, laws, policies**



Federal Watershed Policy

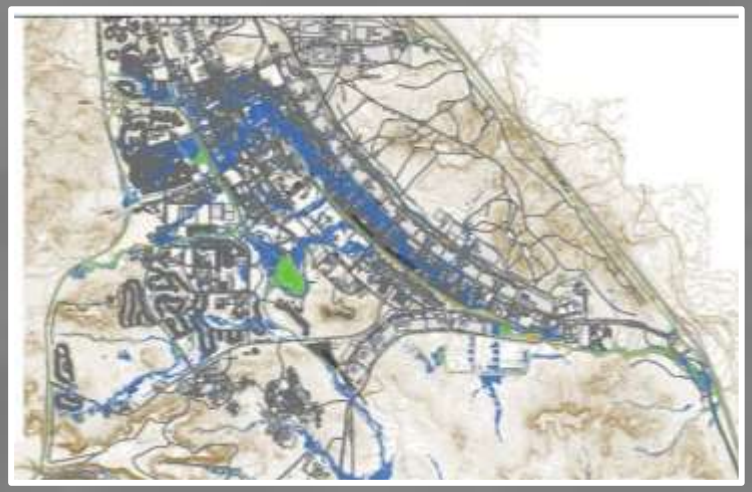
- **Unified Federal Policy for a Watershed Approach to Federal Land and Resource Management (Oct 2000)**
  - **Reduce water pollution**
  - **Conduct assessment of watersheds**
  - **Determine existing conditions**
  - **Assess impacts of current and past actions**
  - **Use results to guide planning and management**
- **Army Regulation 200-1, Environmental Protection and Enhancement (Dec 07)**

  "Installations use a watershed management approach when evaluating projects and programs to satisfy environmental regulations, facility projects, and master planning that may impact the quality of water resources."

Executive Order 11988

- **Floodplain Management (May 77)**
  - **Agency has responsibility to evaluate potential <u>effects of actions in a floodplain</u>**
  - **Ensure that <u>planning programs and budget requests reflect consideration of flood hazards and floodplain management</u>**

San Antonio, TX (FEMA)



Fort Carson, CO (XPSWMM – 3D)

Challenges: EO EISA 07 & 13514

- **Section 438, Energy Independence and Security Act (Dec 07)**
  - **"Stormwater Runoff Requirements for Federal Development Project"**
  - **Development or redevelopment project with footprint > 5,000 sf**
  - **Planning, design, construction, maintenance strategies to maintain or restore predevelopment hydrology**
  - **Temperature, rate, volume, duration of flow**
- **Executive Order 13514, Federal Leadership in Environmental, Energy and Economic Performance (Oct 09)**
  - **Section 2: Improve Water Use Efficiency and Management**
    - **Identify, promote, implement water reuse to reduce potable water use**
  - **Section 14: Stormwater Guidance for Federal Facilities**
    - **Final Technical Guidance on Implementing Section 438 released Dec 09**
    - **15% of existing infrastructure needs to include LID**

WHAT IS (LID) LOW IMPACT DEVELOPMENT?

- **Innovative Stormwater Management approach that manages stormwater at the source.**
- **Utilizing decentralized stormwater techniques to mimic the pre-development hydrologic regime.**
- **The utilization of infiltration, filtration, storage, evaporation and detention to treat stormwater.**

WHAT IS (LID) LOW IMPACT DEVELOPMENT?

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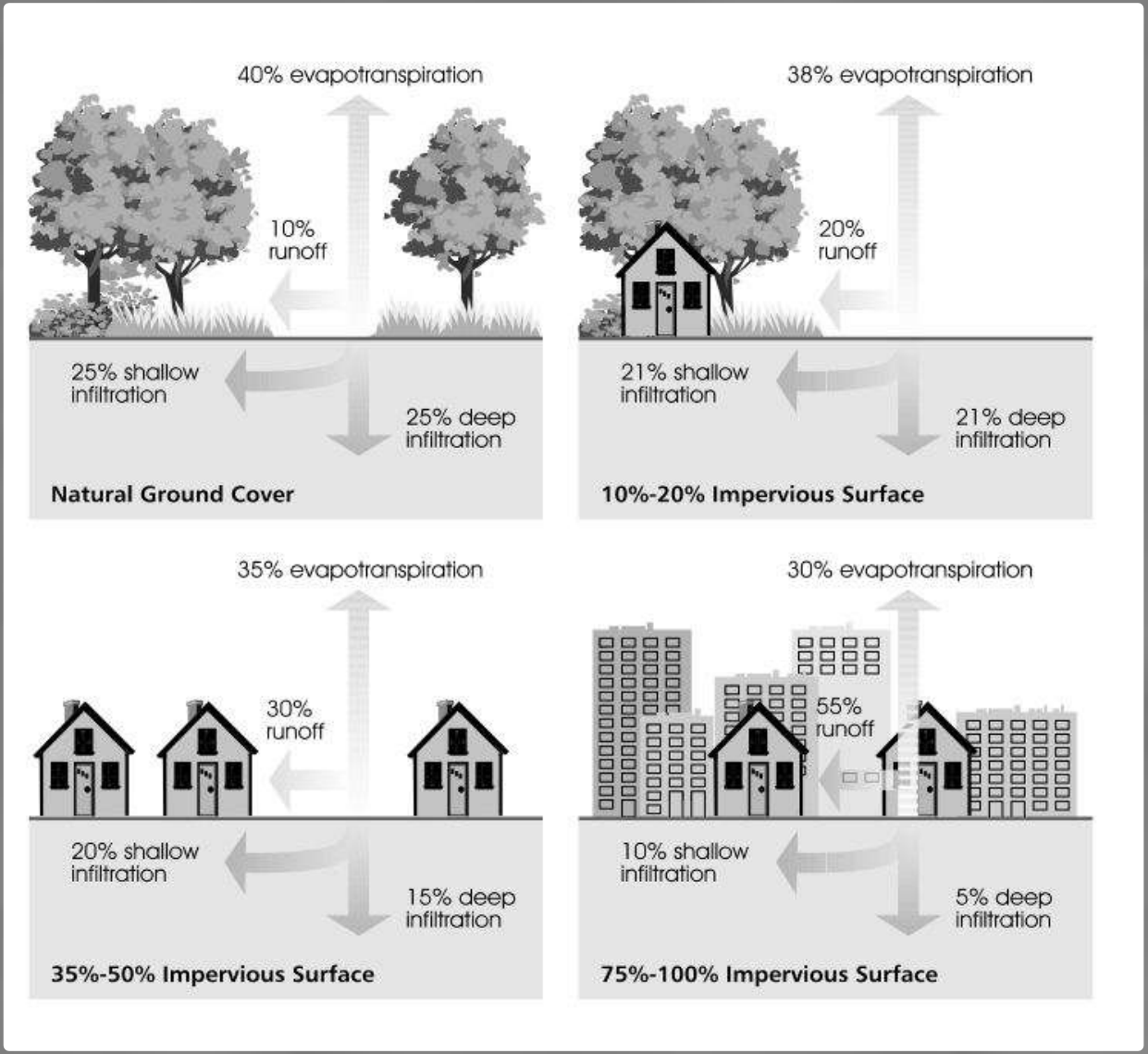
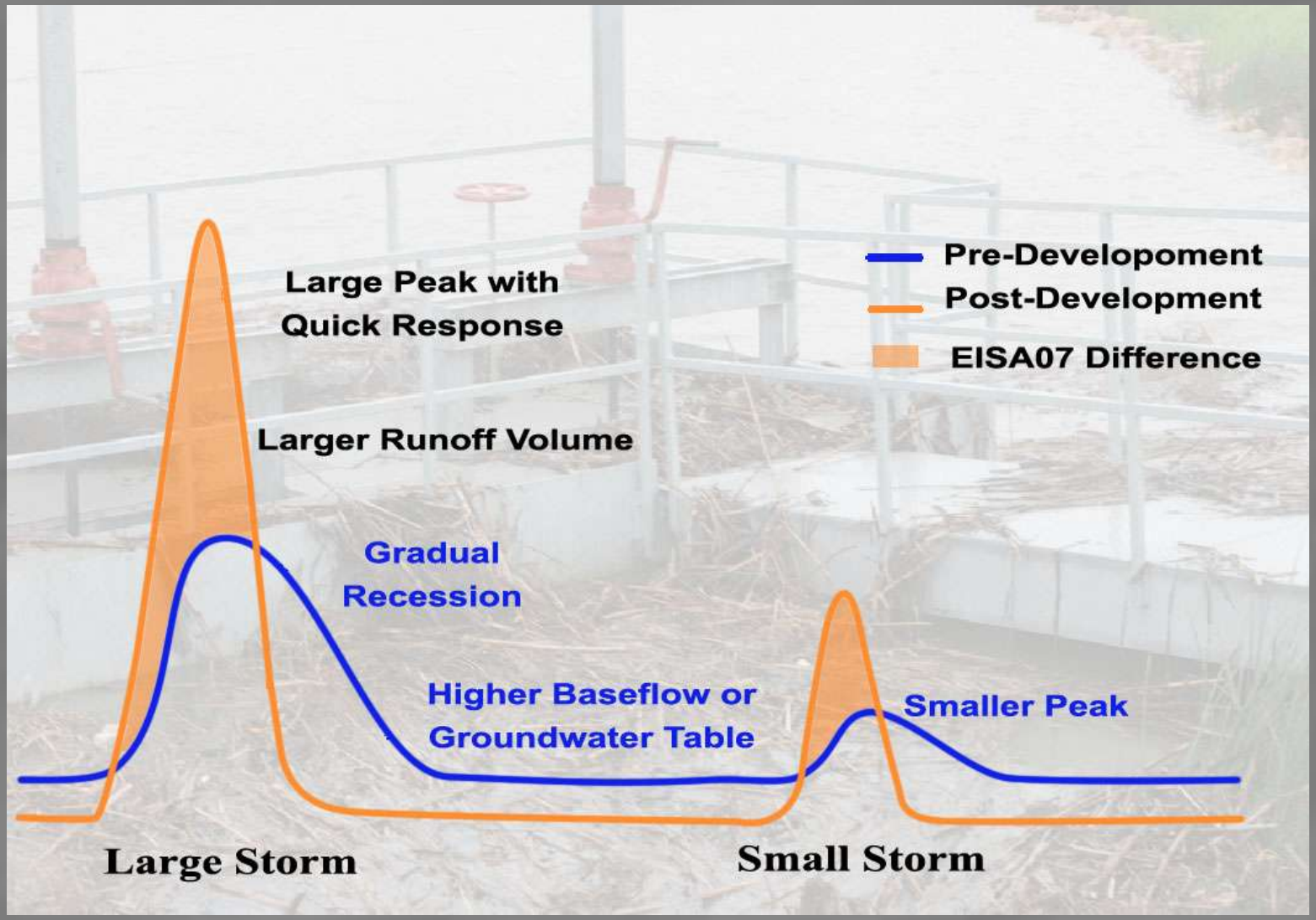
From EISA07, Section 438 Stormwater runoff requirements for Federal development projects

"The sponsor of any development or redevelopment project involving a Federal facility with a footprint that **exceeds 5,000** square feet shall use site planning, design, construction, and maintenance strategies for the property to **maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow.**"

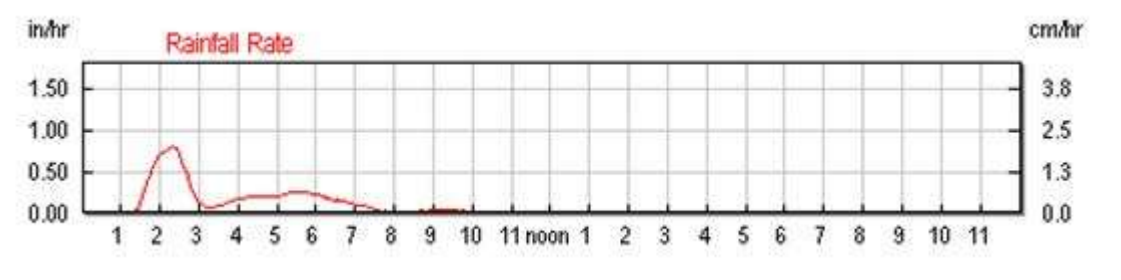
Changes Due to Urbanization

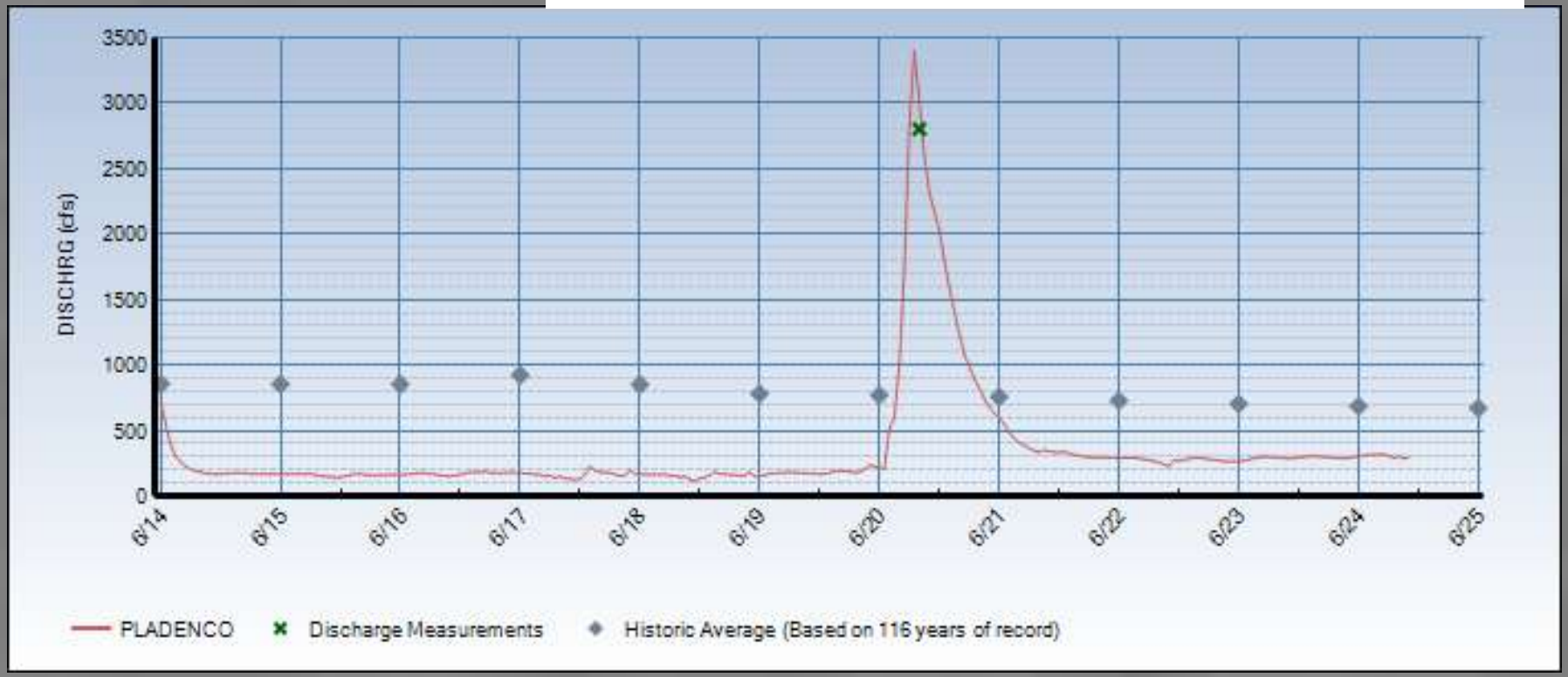


Consequences of Development



Downtown Denver
6 hour storm - 1.6 inches





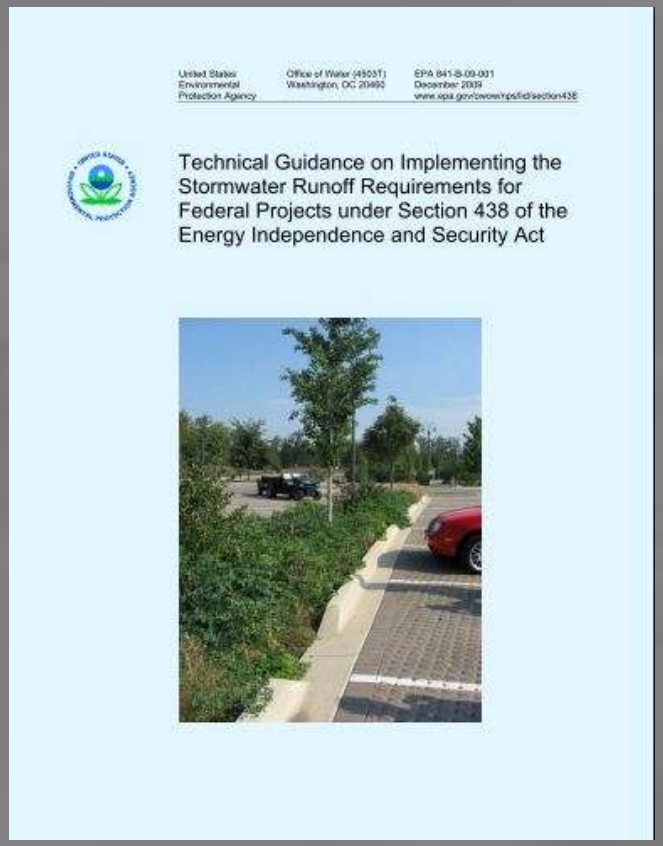
APPLICATION OF LID

- ✓ NEW DEVELOPMENT
- ✓ URBAN RETROFITS
- ✓ REDEVELOPMENT
- ✓ REVITALIZATION

WHERE CAN I USE LIDs

- ✓ OPEN SPACES
- ✓ ROOFTOPS
- ✓ STREETSCAPES
- ✓ PARKING LOTS
- ✓ SIDEWALKS
- ✓ MEDIANS
- ✓ TURNAROUNDS

EISA07 Guidance Document



United States Environmental Protection Agency | Office of Water (4503T) Washington, DC 20460 | EPA 841-B-09-001 December 2009 www.epa.gov/owow/nps/fed/section438

Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act

Option 1 - Utilizing the 95% storm event

Option 2 - Modeling the difference between natural and post construction hydrologic conditions

Fort Carson's Primary LID Parameters

Volume, Volume, Volume

If you remove the initial volume that runs off the site due to impervious surfaces, you in fact will be duplicating the natural hydrology. (initial abstraction)

To accomplish this, the designer must infiltrate or temporarily detain the water so that it can be released within 48 hrs.

Increasing you lag-time increases the soils ability to infiltrate and remove pollutants

Modeling vs. 95 Percentile

Site	Pre Development	Post Development	Retained Volume
Triple Foods	0.69	0.77	**0.08**
95 %			0.33
AFFES Mini Mall	0.52	0.67	**0.16**
95 %			0.21
AFFES Shopping	3.28	3.83	**0.55**
95 %			1.54
MICOF	1.27	1.52	**0.25**
95 %			0.75

LID PLANNING PRINCIPLES

- **Control runoff volumes at the source (many small BMPs)**
- **Disconnect impervious surfaces**
- **Utilization of vegetation for evapotranspiration**
- **Infiltration for groundwater recharge**
- **Direct runoff to hydrologically functional landscapes**
- **Utilization of soil media for biodegradation of pollutants**

Challenges: LEED

- **Federal Sustainable Design Policies**
  - **Federal Leadership in High Performance & Sustainable Building MOU (Jan 06)**
  - **Air Force Sustainable Design & Development Policy Memorandum (July 07)**
  - **USACE LEED Implementation Guide (Jan 08)**
  - **Stormwater Design for LEED-NC (v3)**
    - **SS 6.1, <u>Quantity Control</u> - limit disruption of natural hydrology**
    - **SS 6.2, <u>Quality Control</u> - limit disruption, pollution natural water by managing runoff**
  - **New extra credit points for LEED-NC (v3) for projects that adapt to local conditions or regional priorities**

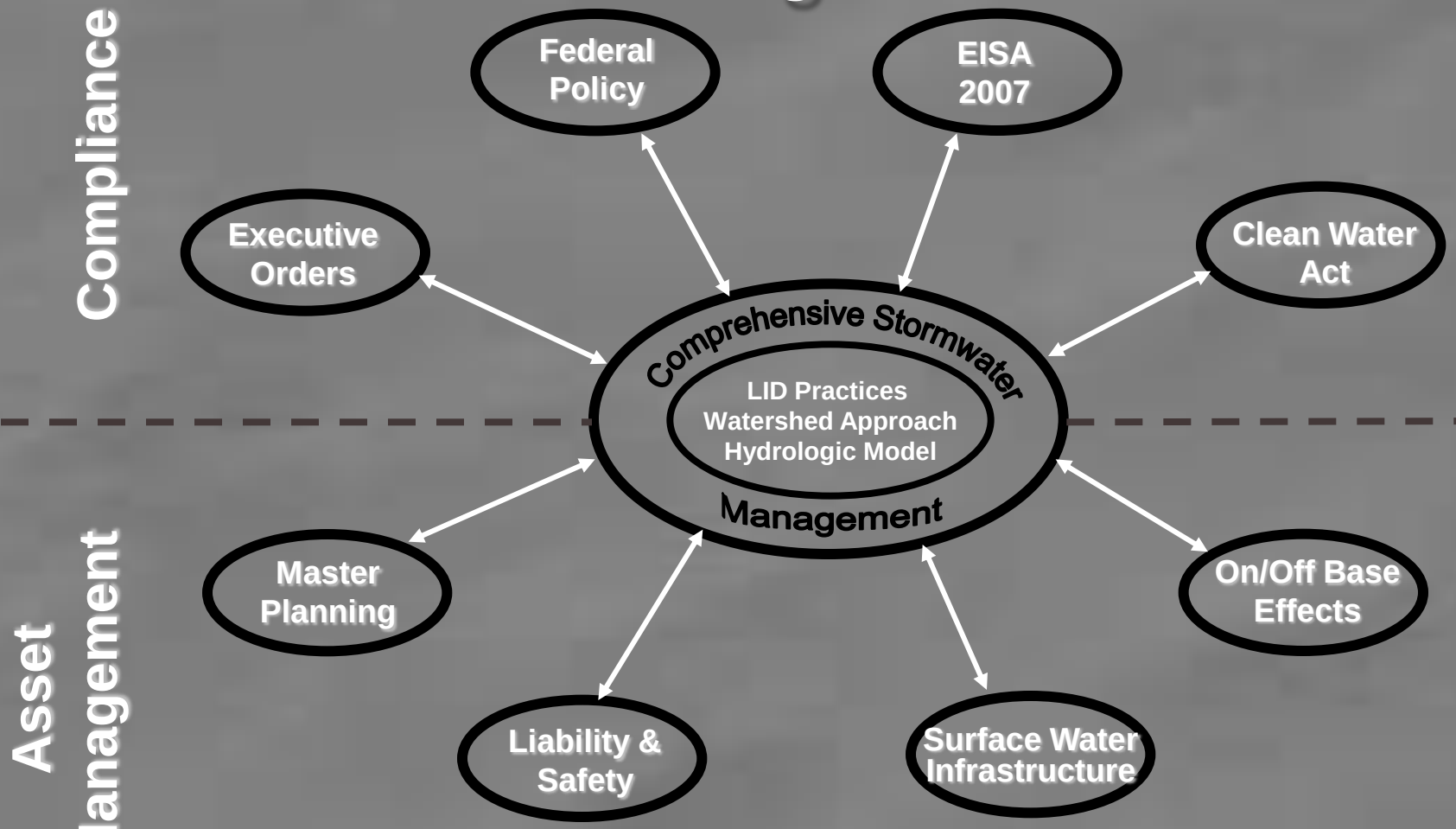
POTENTIAL LEED CREDITS

- **Sustainable Sites- credit 6 "Stormwater Management" (1-2 points)**
- **Sustainable Sites- credit 7 "Landscape & Exterior Design to Reduce Heat Island" (1-2 points)**
- **Water efficiency- credit 1 "Water Efficient Landscaping" (1-2 points)**
- **Innovation & Design Process (1-4 points)**

Challenges: Infrastructure

- **BRAC**
  - New construction (increased NEPA reviews; EISA07 requirements; CWA compliance)
  - Increased impervious areas
- **Aging infrastructure**
  - Undersized and/or deteriorating
  - Not upgraded in response to population growth
  - Lack of maintenance (e.g., culvert cleanouts)
  - Typically ignored until there's a problem
- **Combined federal/municipal infrastructure**
  - Liability concerns - property damage, compliance and water quality, safety
- **Community encroachment**
  - Increased stormwater discharge on/off facility
  - Water quality entering/exiting the facility
- **Receiving waters**
  - TMDLs
  - Critical habitats

Comprehensive Stormwater Management



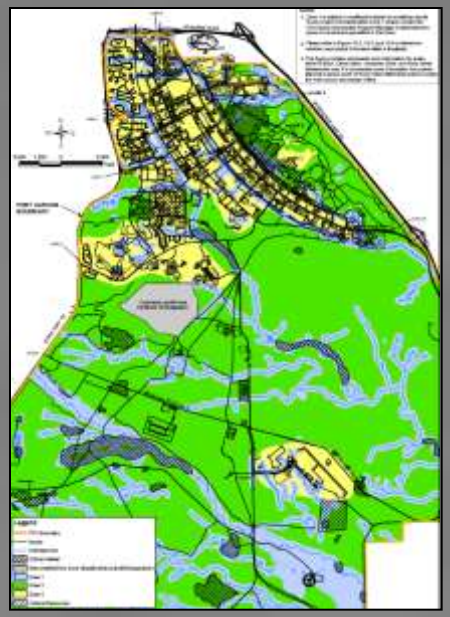
Comprehensive Stormwater Management

- **Comprehensive stormwater management is a watershed-based approach that promotes the use of LID practices and relies on dynamic hydrologic modeling**

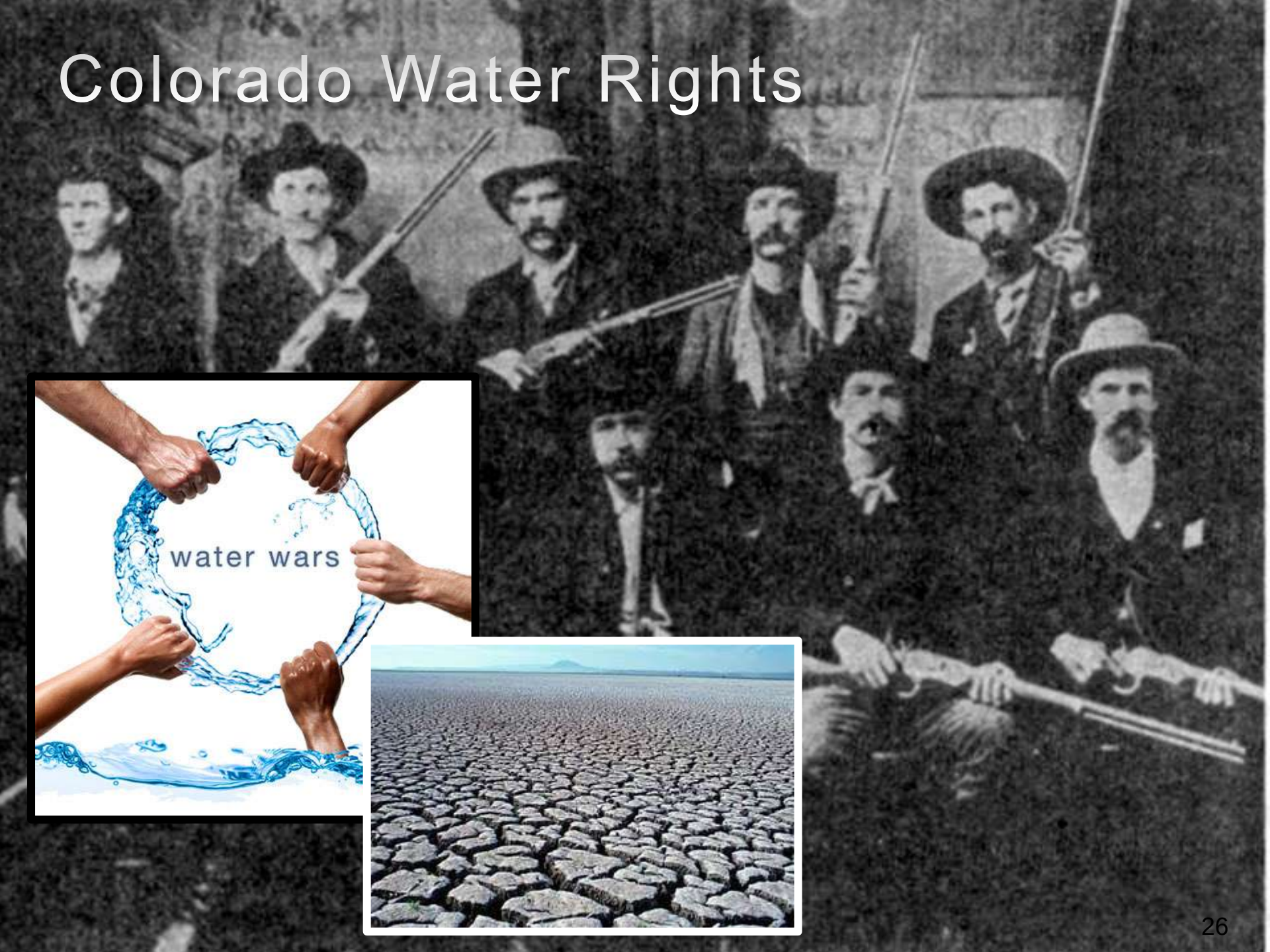
- **Watershed-Based Approach**
  - Matches EPA's vision and Federal policy guidance
  - Management decisions are based on watershed level, not individual site footprint
  - Promotes proactive stormwater management (vs. reactive)
  - Supports master planning/future growth
  - Evaluates adequacy & effectiveness of stormwater infrastructure
  - Better understanding of water quality on and off base (current condition; impacts from proposed actions)
  - Maintain overall health, stability of watersheds and drainages
  - Rebalance/restore hydrologic conditions

Comprehensive Stormwater Management

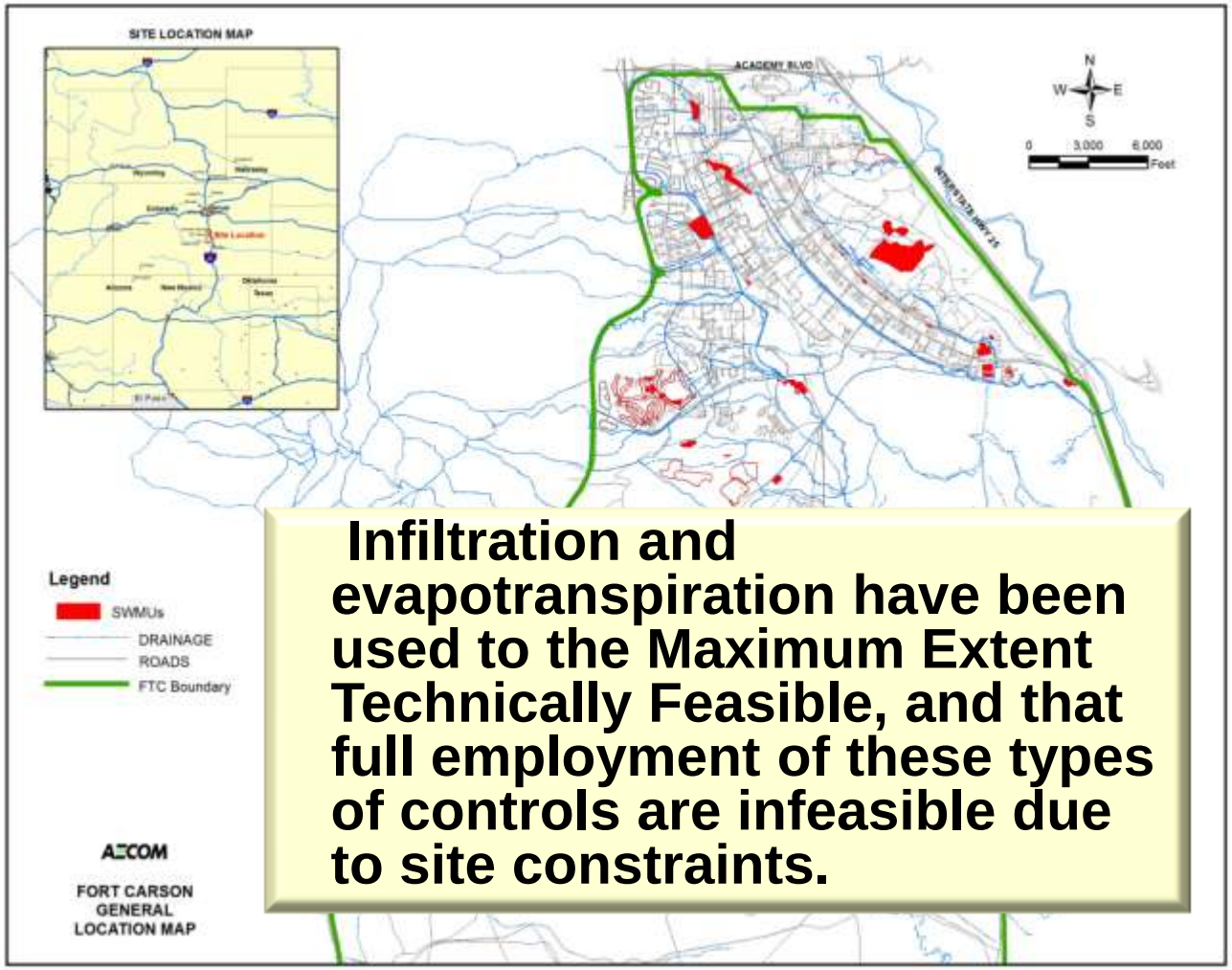
- **Low Impact Development (LID) practices**
  - **Supports watershed-based management**
  - **Dovetails well with CWA - promotes infiltration, reduces runoff, decreases pollutants**
  - **Supports pre-development hydrology requirement (EISA 07)**
  - **Promotes water reuse strategies; reduction in potable water use**
  - **More likely to qualify for LEED credit**
  - **Reduce runoff, load on infrastructure**
  - **Promotes beautifully landscaped areas, wildlife habitat**
  - **BMPs limited to LID practices ensures facility needs are addressed (e.g., state/tribal laws; mission; climate; wildlife; soil types; receiving waters)**



Colorado Water Rights



Exemptions



Infiltration and evapotranspiration have been used to the Maximum Extent Technically Feasible, and that full employment of these types of controls are infeasible due to site constraints.

Groundwater Concerns

- Check for seasonally high/low water table
- Coordinate with geotechnical on perched water tables
- Target > 2 feet below bioretention
- Avoid dewatering and discharging groundwater to storm drain

Questions/Comments

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EPA LID Video

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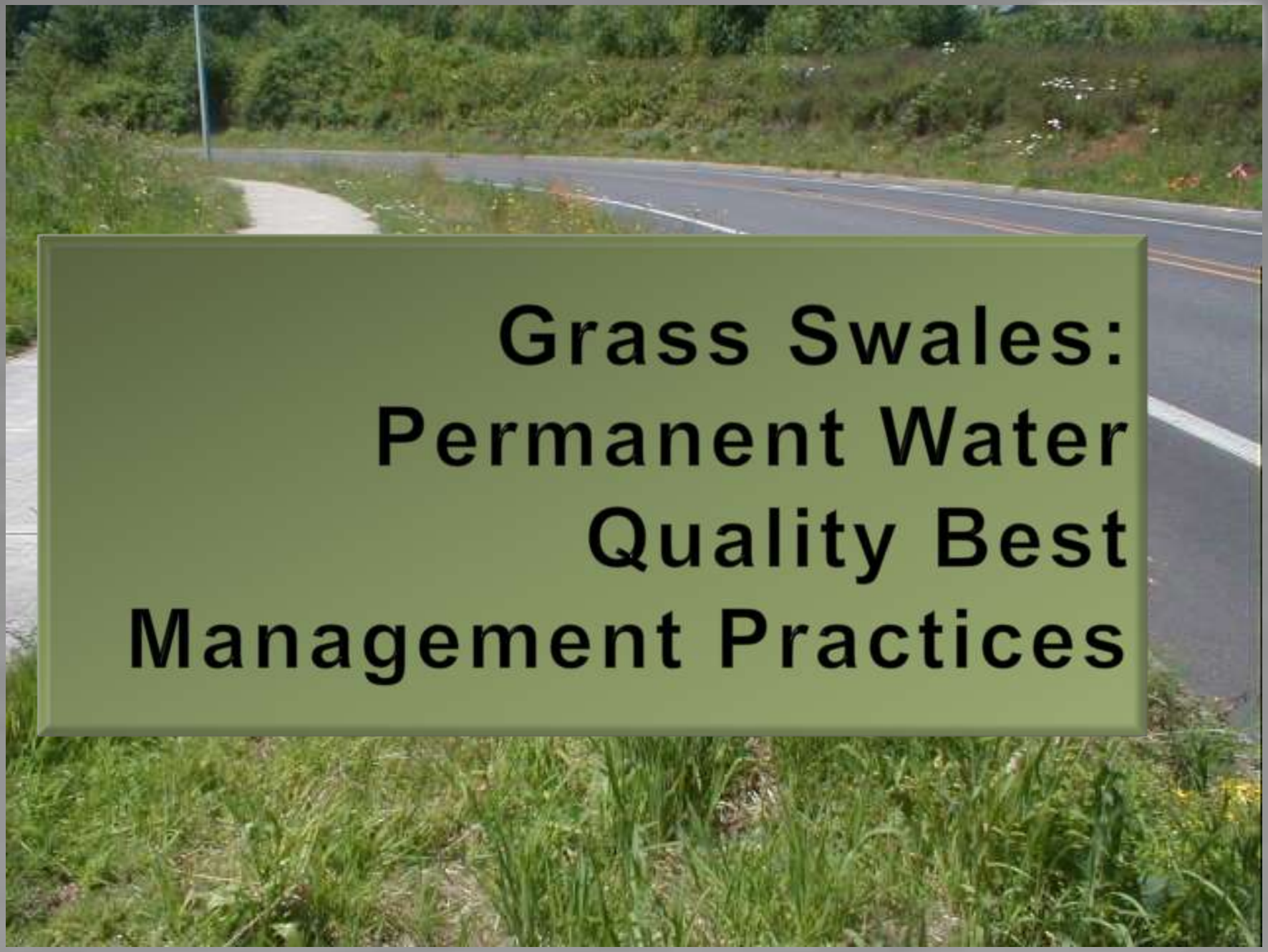
- Berm
- Curb Cuts and other disconnects
- Permeable Pavers
- Geo Textile Grids
- Ditches and Check Dams



Grass Swales: Permanent Water Quality Best Management Practices

Purpose of A Grass Swale

1) **Low Cost, Effective Pollutant Removal**
2) **Conveyance**
3) **NPDES Compliance**

Terms for Grass Swales

Terms vary from state to state. Typical terms include:

- **Grass Swales**
- **Vegetated Swales**
- **Bio-swales**

Photos of Example Grass Swale Applications

(Source: City of Duluth, Minnesota)

Photos of Example Grass Swale Applications
(Source: City of Sandy, Oregon)

Why a Grass Swale?

- **Installation Costs**
- **Effectiveness of Pollutant Removal**
  - **Grass swales are particularly effective to remove heavy metals and suspended solids.**
  - **Heavy metals and suspended solids are typical "pollutants of concern" for roadway runoff.**
- **Site suitability**

Pollutant Removal Rates

- 58% removal of total suspended solids*
- 82% removal of total petroleum hydrocarbons*
- 88% removal of total zinc.*
- 52% average peak flow reduction.*

*Per 2009 annual report from the University of New Hampshire Stormwater Center. See http://ciceet.unh.edu/

Comparison of Pollutant Removal Efficiencies

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UNHSC Pollutant Removal Efficiencies								
Treatment Unit Description	Reference	TSS Total Suspended Solids (% Removal)	TPH-D Total Petroleum Hydrocarbons in the Diesel Range (% Removal)	NO3-N (DIN) Dissolved Inorganic Nitrogen (% Removal)	TZn Total Zinc (% Removal)	TP Total Phosphorus (% Removal)	Average Annual Peak Flow Reduction (% Removal)	Average Annual Lag Time (Minutes)
Conventional Treatment Devices								
Retention Pond	UNH	68	82	33	68	NT	86	455
Stone (rip-rap) Swale	UNH	50	33	NT	64	–	6	7
Vegetated Swale	UNH	58	82	NT	88	NT	52	38
Berm Swale	UNH	50	81	NT	50	8	24	58
Deep Sump Catch Basin	UNH	9	14	NT	NT	NT	NT	NT
Manufactured Treatment Devices (MTDs)								
ADS Infiltration Unit	UNH	99	99	NT	99	81	87	228
StormTech	UNH	80	93	NT	56	49	76	274
Aquafilter	UNH	62	26	NT	52	59	NT	NT
Hydrodynamic Separators	UNH	27	1	NT	24	42	NT	NT
Low Impact Development (LID)								
Surface Sand Filter	UNH	51	98	NT	77	33	69	187
Bioretention								
Bio I - 48" depth	UNH	97	99	44	99	–	75	266
Bio II - 30" depth	UNH	87	99	NT	68	34	79	309
Gravel Wetland	UNH	99	99	98	99	56	87	251
Porous Asphalt	UNH	99	99	NT	75	60	82	1,275
Pervious Concrete	UNH	97	99	NT	99	NT	93	1,144
Tree Filter	UNH	93	99	3	78	NT	NT	62

Installation Costs

- **Installation Costs:**
  - **Consider thinking in terms of $/Acre Treated. Grass swales, extended detention, and constructed wetlands typically have considerably lower $/acre treated than other permanent BMP alternatives. Of these three options, only grass swales can effectively treat small (<1 acre) drainage areas.**
  - **Also consider thinking in terms of conveyance cost requirements. Conveyance systems to send runoff to a centralized treatment area have cost implications. Grass swales can treat runoff immediately and also serve as a conveyance mechanism.**

$/Acre Treated as Analyzed As Part of A Recent Airport Project

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Table 1 - Treatment Control Measure Comparison: Preliminary Comparisons

Post-Construction TCM	Pollutant Removal Efficiency*	Estimated Probable Cost**	Required BMP Site Footprint Area (Acres)	Treated Runoff Area** (Acres)	Installation Cost per Acre Treatedd
Vegetated Swale	Medium	$280,000	2.8	30	$9,333
Sand Filter (Austin Sand)	High	$2,600,000	0.06	30	$86,667
Perlite/Zeolite Filter (StormFilter™)	High	$520,000	underground	30	$17,333
Perlite Filter (AquaFilter™)	High	$171,000	underground	30	$5,700
Bioretention	High	$9,600,000	5.5	30	$320,000
Constructed Wetlands	High	$300,000	3.2	30	$10,000

*Relative removal rate for pollutants of concern. Removal rates for infiltration basin, bioretention and constructed wetlands per California Stormwater Quality Association New Development and Redevelopment Handbook, 2003 (Reference 7). StormFilter and AquaFilter removal rates per vendor.

**Treated area set at 30 acres for all Treatment Control Measures (TCMs) in order to allow for a consistent comparison of costs. Actual area treated will depend on the TCM's interaction with the site geometry. Cost estimates may vary substantially from actual. Per reference 7, costs for StormFilter and AquaFilter assumes installation cost to be 100% of manufacturer's cost. Vegetated swale cost calculated using CALTRANS 2006 unit costs for materials. All other costs per reference 7.

$/Acre Treated as Analyzed As Part of A Recent Airport Project

$/Acre Treated (from cost opinion, previous slide):

Vegetated Swale: $9,300

Sand Filter: $86,700

What Design Criteria is Available For Grass Swales?

- **Swale geometry: Consider following UDFCD design criteria.**
- **Swale length: No detailed local guidance available currently. Consider following industry standard practice.**

How Long Does a Grass Swale Need to Be?

- **Target Hydraulic Contact Time (Time Water is in contract with grass)**
  - **Research indicates that pollutant removal, via filtration from the grass, is accomplished in 5 minutes**
  - **Typical national standard calls for factor of safety of 2, setting target at 10 minutes**
- **Typically, 100 feet to 500 feet is sufficient to accomplish 10 minutes hydraulic contact time if good design strategy is employed. Length will vary depending on quantity of runoff treated and swale geometry**

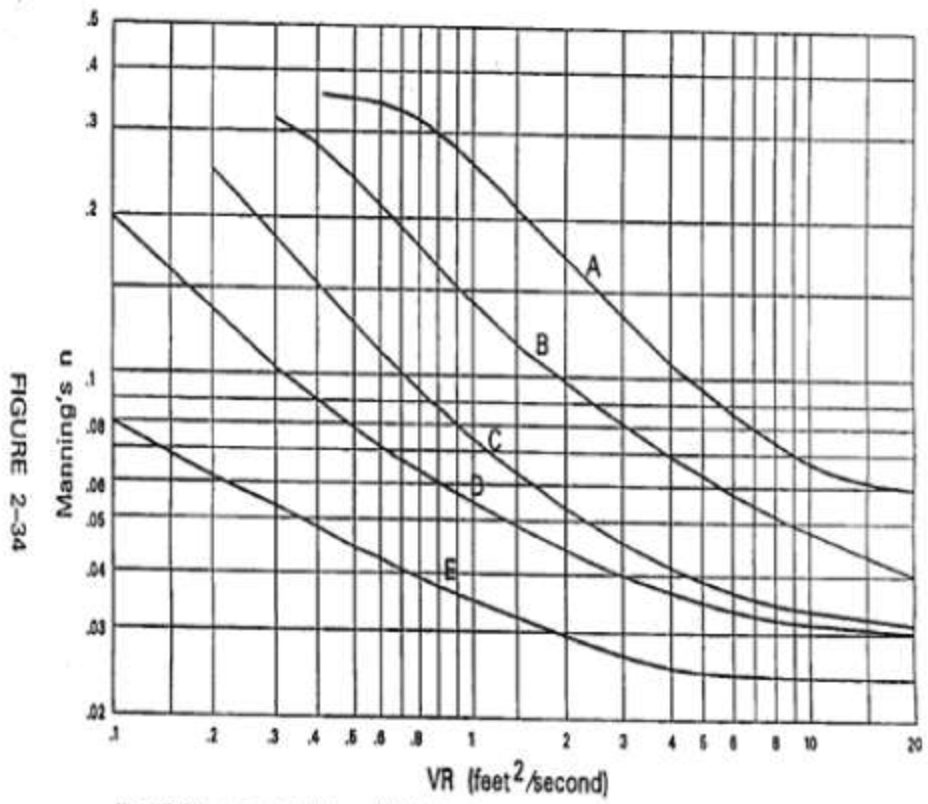
Strategies to Increase Hydraulic Contact Time

- **Minimize longitudinal slope**
- **Maximize swale length**
- **Include check structures in high slope applications**
- **As needed to accomplish above, design "special" ditches, or ditches with longitudinal slopes differing from overall roadway longitudinal roadway slope.**
- **Where possible, determine an 80th Percentile Runoff Event (typically 0.5 inches/hour in Colorado). This event should be significantly smaller than the 2-Year event and will require a shorter length to treat.**
- **Take advantage of variable Manning's N with depth and vegetal retardance.**

Vegetal Retardance

- To a runoff flowing at a depth of 1’, typical of a minor runoff event, grass Manning’s N will be roughly 0.03 to 0.06, depending on grass species and height.
- To water flowing at 1” depth, typical of a water quality event, Manning’s n will be closer to 0.15. This will slow down the water considerably and increase hydraulic contact time for the water quality runoff event.

Vegetal Retardance



Note: VR is the product of velocity and hydraulic radius
Source: Horner, 1993

The Relationship of Manning's n with VR for Various Degrees of Flow Retardance (A–E)

Grass Swale Design Calculation Procedure

- **Step 1: Determine runoff rate, in cubic feet/second, for**
  - **Water quality event (Typically Assumes 0.5”/Hour of Precipitation). The event that will cover eight out of every 10 storms.**
  - **Minor storm event (5-year or 10-year event).**
  - **Major runoff event (50-year to 100-year event).**

Grass Swale Design Calculation Procedure

- **Step 2: Determine velocity for water quality event by using guess and check method.**
  - **Assume a manning's N.**
  - **Calculate velocity (V) and hydraulic radius (R) for the swale using the water quality event runoff.**
  - **Calculate V*R, and use the product to determine Manning's N Using Vegetal Retardance chart**
  - **Is Manning's N (assumed) = Manning's N (calculated)?**
    - **If so, move to step 3.**
    - **If not, assume the calculated Manning's N and repeat step 2.**

Grass Swale Design Calculation Procedure

- **Step 3: Determine hydraulic contact time**
  - **T = Swale Length/Swale Velocity**
  - **If T > 10 minutes, then the swale is definitely long enough and will meet typical national design standards.**
  - **If T < 5 minutes, then the swale may not be providing optimum pollutant removal. Consider revising swale geometry, revising swale length, or taking other steps to reduce swale velocity**

Grass Swale Design Calculation Procedure

- **Step 4: Check swale for minor and major storm capacity. Use conventional (0.03 to 0.06) Manning's N assumptions**

Example Grass Swale Design Calculation

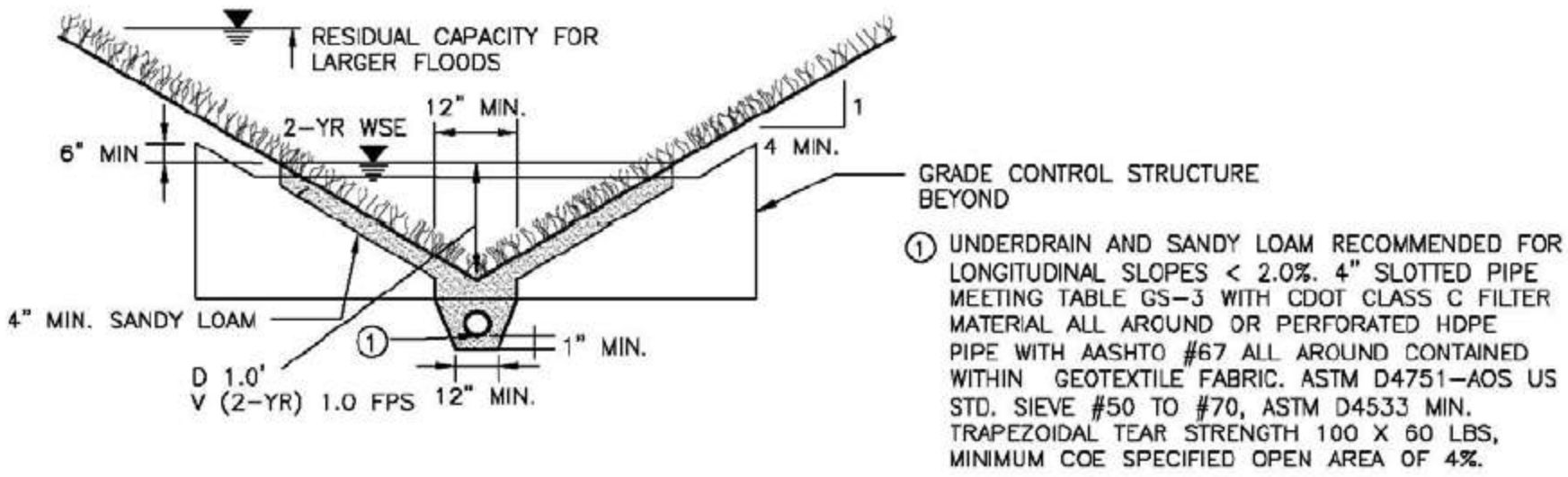
Table 1: Vegetated Swale Hydraulic Contact Time

Swale ID		Hydrology						Hydraulics								Result
		Area														
Storm System	Swale ID	Pervious	Impervious	Total	C	Tc	Runoff Water Quality	Grass Swale Length	Bioswale Longitudinal Grade	Bottom Width	Sideslopes (H:V)	Hydrualic Radius	VR	Manning's n Water Quality	Velocity Water Quality	Water Quality Hydraulic Contact Time**
		Acres				Minutes	cfs	ft	ft/ft	ft	ft/ft	(ft)	(ft^2/s)			Minutes
1	Grass Swale	0.00	0.09	0.09	0.90	5.00	0.040	100	0.0276	0	4	0.12	0.018	0.4	0.15	11

**Minimum 10 minutes.

Infiltration Components

- **Infiltration components are often added per various local criteria**

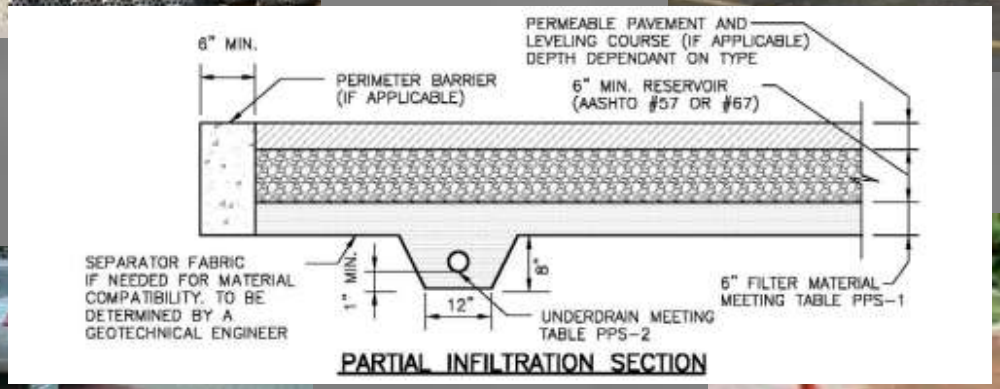


Are infiltration components needed?

- For low longitudinal slope applications, infiltration components can be helpful to clear potential puddles.
- Infiltration components may also provide additional pollutant removal beyond the filtering provided by the grass.
- Consider size of tributary drainage area.

Questions?

Permeable Pavements



Permeable Pavements

- **Permeable Pavement System – is a general term to describe any one of several pavements that allow for the movement of water into layers below the pavement surface. (UDFCD Vol. III)**

- **Benefits –**
  - **Volume Reduction**
  - **Treatment**
  - **Water Quality Capture Volume**
  - **Reduce Effective Impervious**

Photograph PPS-1. The reservoir layer of a permeable pavement provides storage volume for the WQCV. Photo courtesy of Muller Engineering and Jefferson County Open Space.

Types of Permeable Pavements

- **Permeable Interlocking Concrete Pavement (PICP)**
- **Concrete Grid Pavement**
- **Pervious Concrete**
- **Porous Gravel**
- **Reinforced Grass**
- **Pervious Asphalt**

Site Selection

- **Consult a Geotechnical Engineer for**
  - **Pavement Design**
  - **Suitability of Soils**
  - **Identifying Potential Impacts**
  - **Establishing Minimum Distance between BMP and Structure**

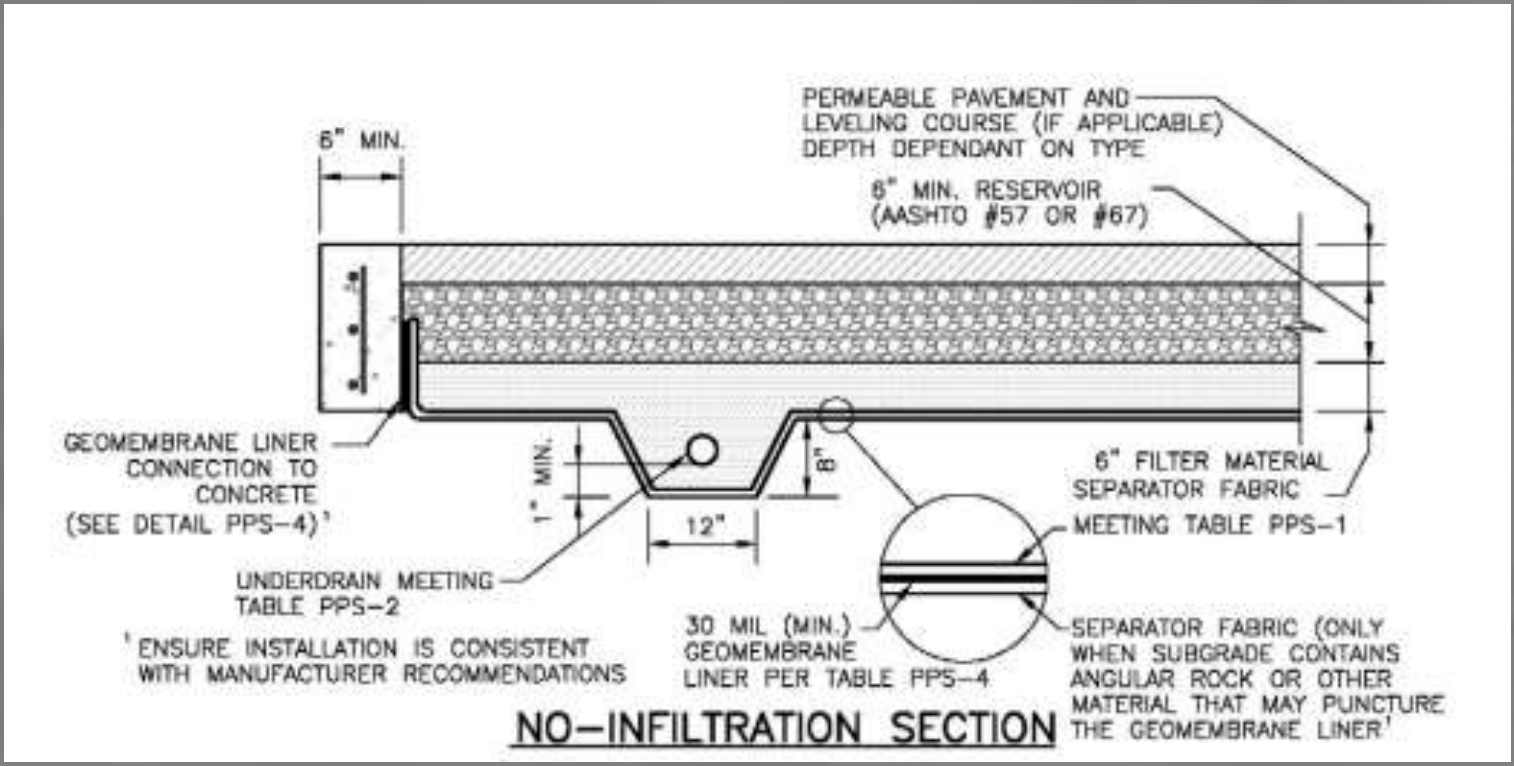
- **Alternative to conventional pavement in pedestrian areas and lower-speed vehicle areas**
  - **Not appropriate where sediment-laden runoff can clog system**
  - **Not appropriate when erosive conditions such as steep slopes and/or sparse vegetation drain to permeable pavement**
  - **Sites where land use or activities cause stormwater infiltration to contaminate or is into contaminated groundwater special design to allow no infiltration is required**

Design Procedure

- **Determination of No-infiltration, Partial Infiltration or Full Infiltration**

- **No-Infiltration Section**
  - **Include an underdrain and impermeable liner that prevents infiltration of stormwater into subgrade soils**
  - **Land use activities could contaminate groundwater if stormwater allowed to infiltrate**
  - **Permeable pavement is located over potentially expansive soils and potentially damage the permeable pavement system or adjacent structures**

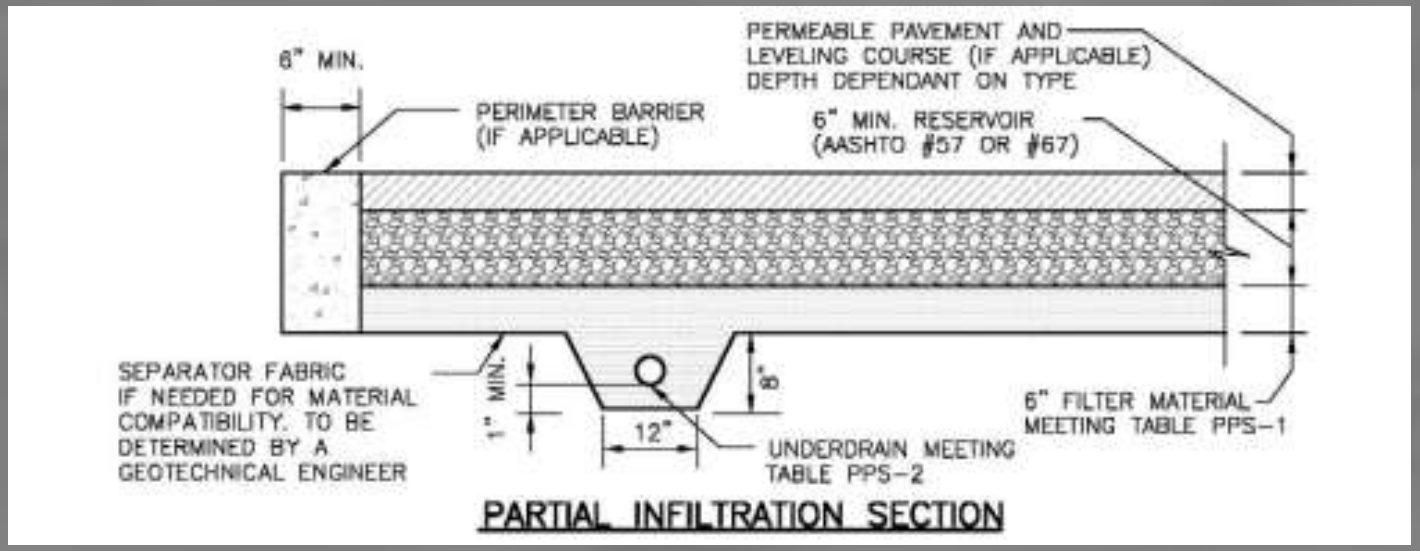
Design Procedure (cont)



Source UDFCD Vol III

Design Procedures (cont)

- **Partial Infiltration Section**
  - **No impermeable liner and allows some infiltration**
  - **Stormwater that does not infiltrate is collected and removed by an underdrain system**



Source UDFCD Vol III

Design Procedures (cont)

- **Full Infiltration Section**
  - **Designed to infiltrate the water stored in the voids of the pavement into the subgrade below**
  - **Recommended that the minimum infiltration rate of 2 times the rate needed to drain the WQCV over 12 hours**

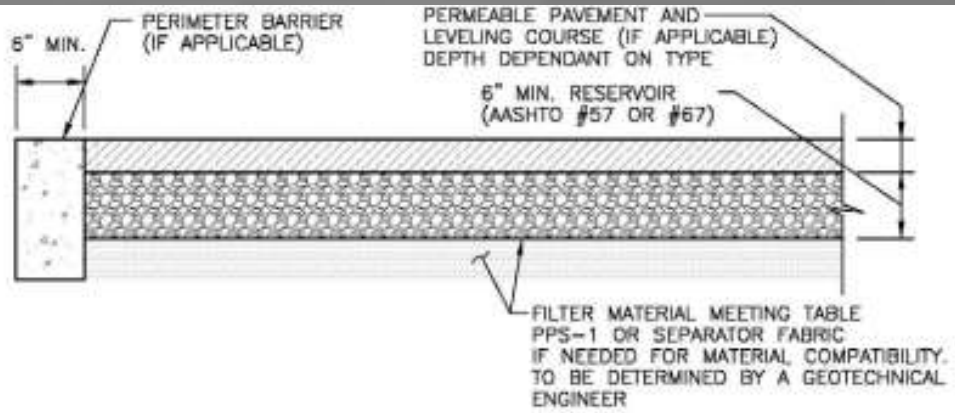


Figure PPS-1. Permeable Pavement Sections

Subsurface Investigation

- **Review geological and geotechnical information to assess near surface soil, bedrock and groundwater conditions that may be encountered and anticipated ranges of infiltration rate for those materials**

- **Exploratory borings or pits to characterize conditions beneath the subgrade and develop requirements for subgrade preparation**
  - **1 bore for every 40,000 SF**
  - **Minimum 2 bore pits for sites between 10,000 and 40,000 SF**
  - **5 feet below bottom of base and at least 20 ft in areas of expansive soils**

Subsurface Investigation(cont)

- **The following Laboratory Tests on samples from the borings shall be completed to characterize the subgrade, evaluate the possible section type and to assess subgrade conditions for supporting traffic loads**
  - **Moisture Content (ASTM D 2216)**
  - **Dry Density (ASTM D 2936)**
  - **Atterberg Limits (ASTM D 4318)**
  - **Gradation (ASTM D 6913)**
  - **Swell Consolidation (ASTM D 4546)**
  - **Subgrade Support Testing (R-value, CBR or unconfined compressive strength)**
  - **Hydraulic Conductivity**
- **For full infiltration perform on-site infiltration tests using a double-ring infiltrometer (ASTM D 3385)**

Required Volumes

- **WQCV based on a 12 Hour drain time**
  - **Maximum recommended ratio for tributary impervious area to permeable pavement area is 2**

Required Storage Volume: Provide the WQCV based on a 12-hour drain time.

- Find the required WQCV (watershed inches of runoff). Using the effective impervious area of the watershed area, use Figure 3-2 located in Chapter 3 to determine the WQCV based on a 12-hour drain time. The maximum recommended ratio for tributary impervious area to permeable pavement area is 2.0. Higher loading is not recommended, as it may increase the required maintenance interval.

- Calculate the design volume as follows:

$$V = \left[\frac{\text{WQCV}}{12}\right] A \qquad \text{Equation PPS-1}$$

Where:

A = watershed area tributary to the permeable pavement (ft^2)

V = design volume (ft^3)

- Add flood control volume if desired. When designing for flood control volumes, provide an overflow that will convey runoff in excess of the WQCV directly into the reservoir. A gravel strip or inlet that is connected to the reservoir can provide this overflow.

Source UDFCD Vol III

Reservoir Depth

- **Flat or stepped installations (0% slope at reservoir/ subgrade interface)**

For flat or stepped installations (0% slope at the reservoir/subgrade interface):

$$V = P\left[\frac{D-1}{12}\right]A$$

Equation PPS-2

Where:

V = volume available in the reservoir (ft^3)

P = porosity, ≤0.30 for porous gravel, ≤0.4 for all other pavements using AASHTO No. 57 or No. 67 coarse aggregate in the reservoir

D = depth of reservoir (in)

A = area of the permeable pavement (ft^2)

Source UDFCD Vol III

Reservoir Depth (cont)

- **Sloped installations**
  (slope of the reservoir/ subgrade interface > 0%)

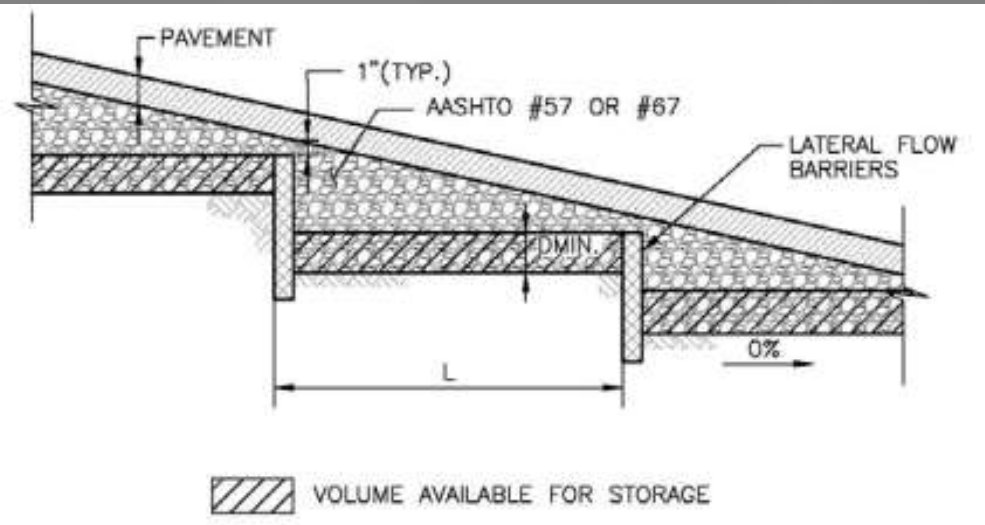


Figure PPS-2. Permeable Pavement Profile, Stepped Installation

Reservoir Depth (cont)

$$V = P\left[\frac{D - 6sL - 1}{12}\right]A$$ Equation PPS-3a

While:

$$L < \frac{2\ \mathrm{WQCV}}{sAP}$$ Equation PPS-3b

Where:

V = volume available in the reservoir (ft^3)

P = porosity, ≤0.30 for porous gravel, ≤0.4 for all other pavements using AASHTO No. 57 or No. 67 coarse aggregate in the reservoir

s = slope of the reservoir/subgrade interface (ft/ft)

D = depth of the reservoir (in)

L = length between lateral flow barriers (see step 4) (ft)

A = area of the permeable pavement (ft^2)

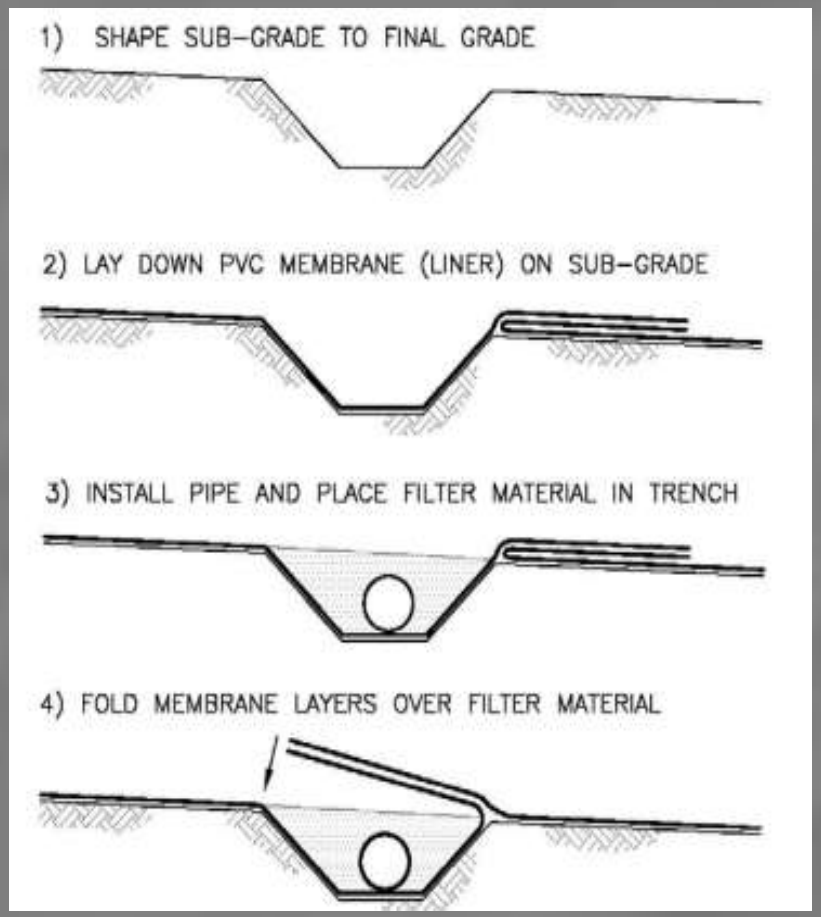
WQCV = water quality capture volume (ft^3)

Source UDFCD Vol III

Lateral Flow Barriers

- **Construct lateral flow barriers using concrete walls or 30 mil PVC geomembrane,**
  - **Parallel to contours (normal to flow)**
  - **Use when reservoir/ subgrade interface greater than 0%**
  - **Spaced per Eq PPS-3b**
  - **Exception is reinforced grass pavement**

Lateral Flow Barriers (cont)



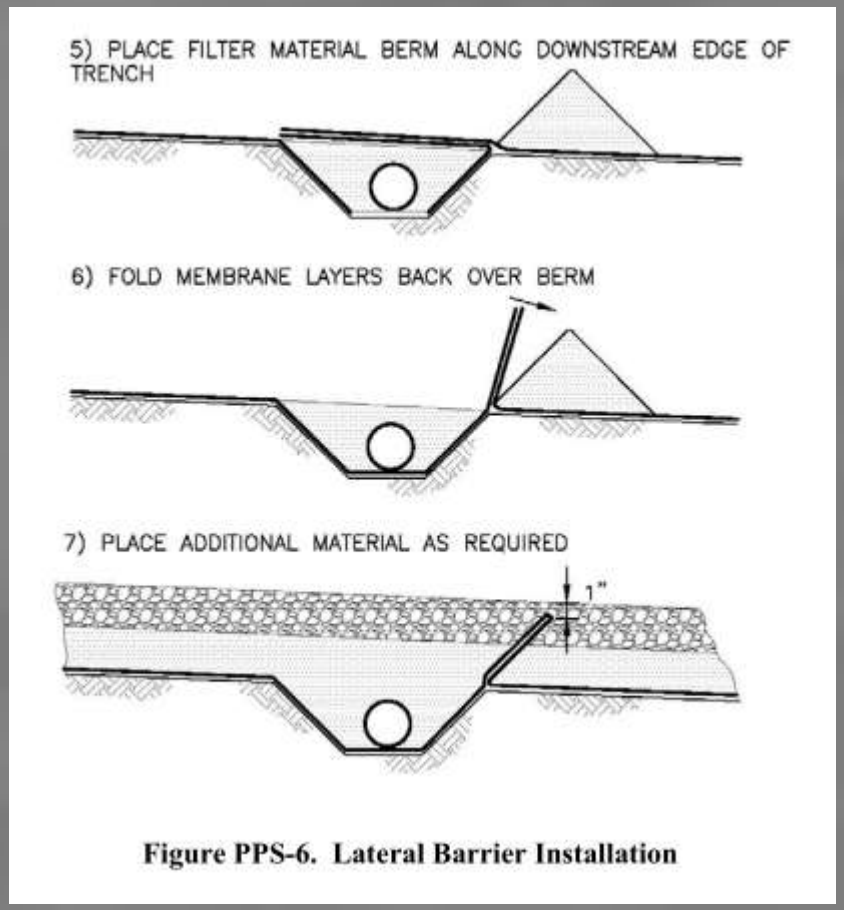


Figure PPS-6. Lateral Barrier Installation

Source UDFCD Vol III

Perimeter Barrier

- **Perimeter Barriers**
  - **Reinforced concrete barrier on all sides of pavement system is required for all no-infiltration conditions**
  - **For PICP and concrete grid pavement a barrier is required to restrain movement of pavers and grids**
  - **In Vehicle areas use Precast, cast in place concrete or cut stone barriers**

Filter Material and Underdrain System

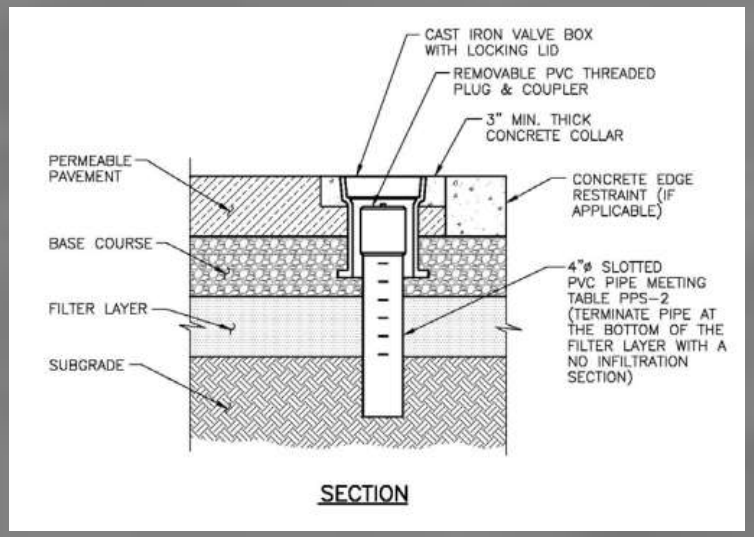
- **Aggregate filter layer and underdrain are required for all partial and no-infiltration sections**
- **Filter layer provides pollutant removal**
- **Underdrain should be placed below a 6-inch thick layer of CDOT Class C filter material meeting the gradation in table PPS-1**

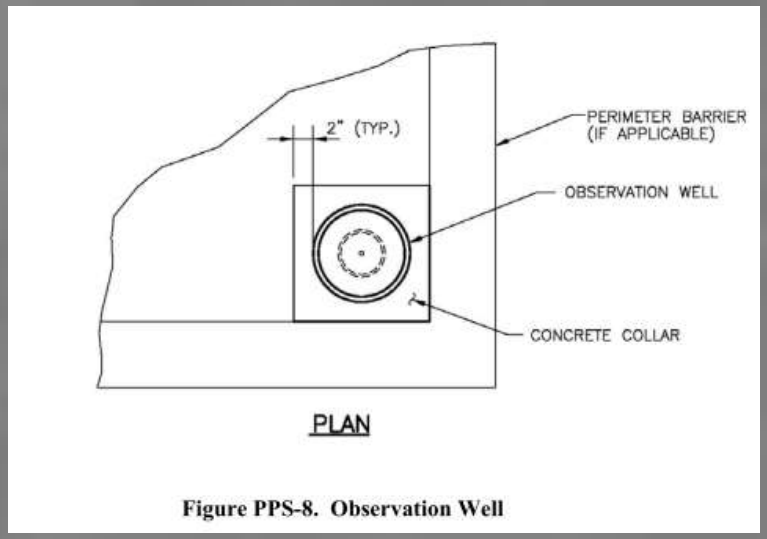
Table PPS-1. Gradation Specifications for Class C Filter Material (Source: CDOT Table 703-7)

Sieve Size	Mass Percent Passing Square Mesh Sieves
19.0 mm (3/4")	100
4.75 mm (No. 4)	60 – 100
300 µm (No. 50)	10 – 30
150 µm (No. 100)	0 – 10
75 µm (No. 200)	0 - 3

Filter Material and Underdrain System (cont)

- **Provide clean-outs to allow for inspection (by camera) of drainpipe system during and after construction to ensure that pipe was not crushed or disconnected during construction and to allow for maintenance.**
- **Use Class C filter material with slotted pipe that meets the slot dimension provided in Table PPS-2 will eliminate the need for aggregate layer wrapped geotextile fabric**





Source UDFC Vol III

Slotted Pipe

- **Table PPS-2 Dimensions for Slotted Pipe**

Table PPS-2. Dimensions for Slotted Pipe

Pipe Diameter	Slot Length[1]	Maximum Slot Width	Slot Centers[1]	Open Area[1] (per foot)
4"	1-1/16"	0.032"	0.413"	1.90 in^2
6"	1-3/8"	0.032"	0.516"	1.98 in^2

[1] Some variation in these values is acceptable and is expected from various pipe manufacturers. Be aware that both increased slot length and decreased slot centers will be beneficial to hydraulics but detrimental to the structure of the pipe.

Source UDFCD Vol III

Impermeable Geomembrane Liner

- **For no-infiltration sections install a 30 mil (minimum) PVC geomembrane liner per Table PPS-4 on the bottom and sides of the basin extending up at least to the top of the filter layer**

Table PPS-4. Physical Requirements for Geomembrane

Property	Thickness 0.76 mm (30 mil)	Test Method
Thickness, % Tolerance	±5	ASTM D 1593
Tensile Strength, kN/m (lbs/in) width	12.25 (70)	ASTM D 882, Method B
Modulus at 100% Elongation, kN/m (lbs/in)	5.25 (30)	ASTM D 882, Method B
Ultimate Elongation, %	350	ASTM D 882, Method A
Tear Resistance, N (lbs)	38 (8.5)	ASTM D 1004
Low Temperature Impact, °C (°F)	-29 (-20)	ASTM D 1790
Volatile loss, % max.	0.7	ASTM D 1203, Method A
Pinholes, No. Per 8 m^2 (No. per 10 sq. yds.) max.	1	N/A
Bonded Seam Strength, % of tensile strength	80	N/A

Source UDFCD Vol III

Geotextile Separator Fabric

- **Place a CDOT Class B geotextile separator fabric per Table PPS-3 above the geomembrane to protect it from being punctured during the placement of the filter material**

Table PPS-3. Physical Requirements for Separator Fabric[1]

Property	Class B		Test Method
	Elongation < 50%[2]	Elongation > 50%[2]	
Grab Strength, N (lbs)	800 (180)	510 (115)	ASTM D 4632
Puncture Resistance, N (lbs)	310 (70)	180 (40)	ASTM D 4833
Trapezoidal Tear Strength, N (lbs)	310 (70)	180 (40)	ASTM D 4533
Apparent Opening Size, mm (US Sieve Size)	AOS < 0.3mm (US Sieve Size No. 50)		ASTM D 4751
Permittivity, sec^{-1}	0.02 default value, must also be greater than that of soil		ASTM D 4491
Permeability, cm/sec	k fabric > k soil for all classes		ASTM D 4491
Ultraviolet Degradation at 500 hours	50% strength retained for all classes		ASTM D 4355

[1] Strength values are in the weaker principle direction
[2] As measured in accordance with ASTM D 4632

Source UDFCD III

Outlet

- **WQCV from each cell should be released slowly to drain the cell in approximately 12 hours**
- **Orifice at the outlet of the underdrain can be used to control each cell to provide detention and slow release of the WQCV to offset hydromodification**
- **Minimum orifice size is 3/8”**
- **If lateral walls are required each cell is a separate system**
- **If design include multiple cells the orifice calculation should be completed for each cell using the WQCV and the V_{total} for that cell**

Outlet Structure

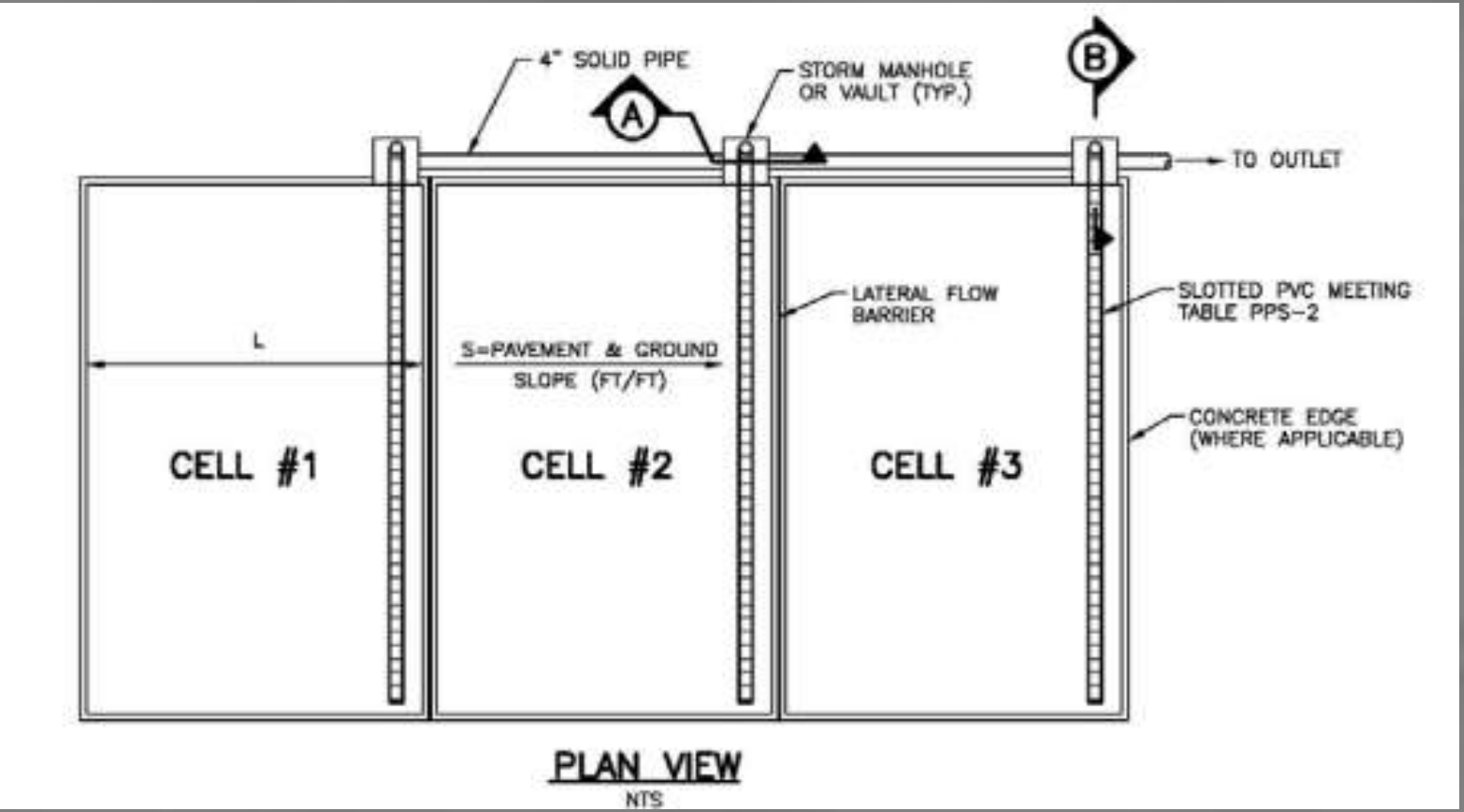


Figure PPS-7 Underdrain System layout and Outlet details Source UDFCD Vol III

Outlet Structure

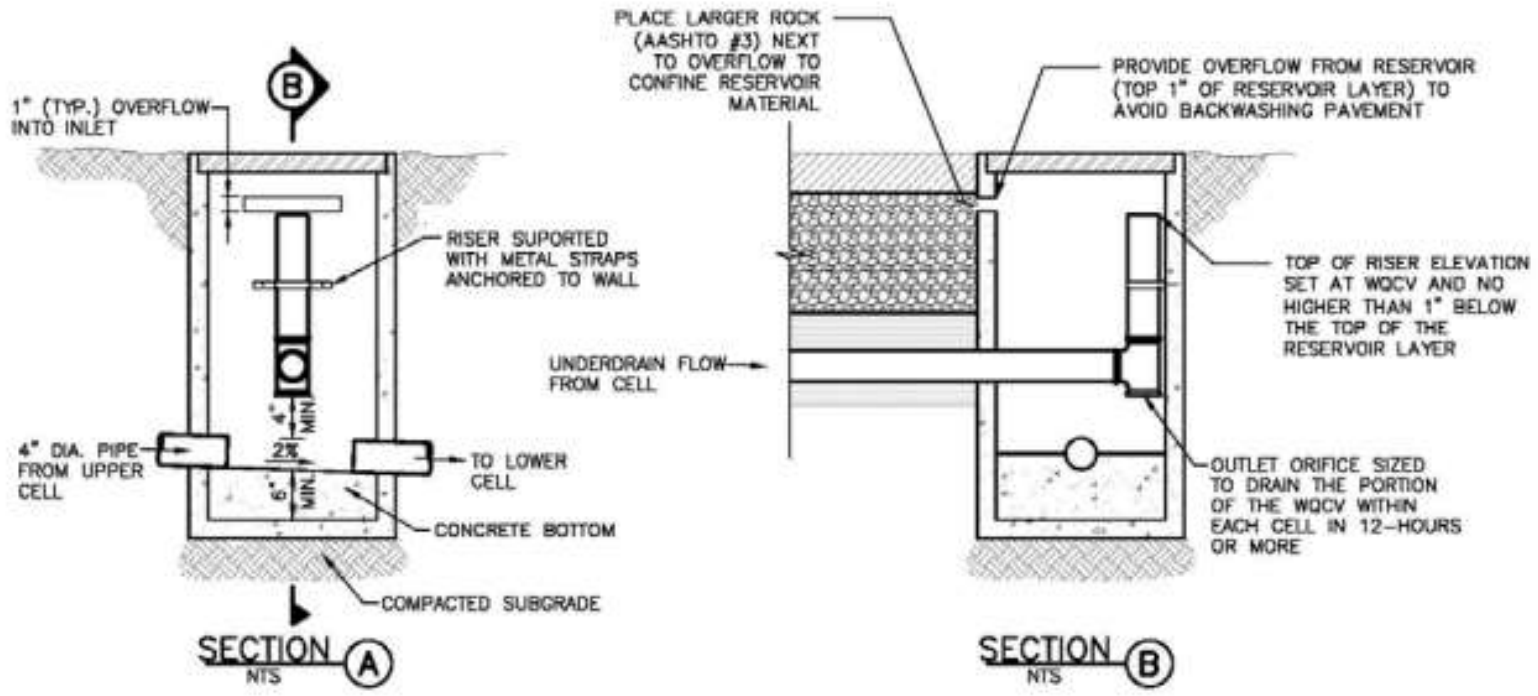


Figure PPS-7. Underdrain System Layout and Outlet Details

Depth of WQCV

For calculating depth of the WQCV using a flat/stepped installation, see Figure PPS-2:

$$d = \frac{12\ \mathrm{WQCV}}{PA}$$ Equation PPS-4

Where:

d = depth of WQCV storage in the reservoir (in)

P = porosity, ≤0.30 for porous gravel, ≤0.4 for all other pavements using AASHTO No. 57 or No. 67 coarse aggregate in the reservoir

A = area of permeable pavement system (ft^2)

WQCV = water quality capture volume (ft^3)

For calculating depth of the WQCV using a sloped installation, see Figure PPS-3:

$$d = 6\left[\frac{2\ \mathrm{WQCV}}{PA}\right] + sL$$ Equation PPS-5

Where:

d = depth of WQCV storage in the reservoir (in)

A = area of permeable pavement system (ft^2)

s = slope of the reservoir/subgrade interface (ft/ft)

L = length between lateral flow barriers (see step 4) (ft)

WQCV Orifice Sizing

For calculating the diameter of the orifice for a 12-hour drain time (Use a minimum orifice size of 3/8 inch to avoid clogging.):

$$D_{12\ \text{hour drain time}} = \sqrt{\frac{V}{1414\, y^{0.41}}}$$ Equation PPS-6

Where:

D = diameter of the orifice to drain a volume in 12 hours (in)

Y = distance from the lowest elevation of the storage volume (i.e. the bottom of the reservoir) to the center of the orifice (ft)

V = volume (WQCV or the portion of the WQCV in the cell) to drain in 12 hours (ft^3)

Source UDFCD Vol III

Design Example

AECOM

Design Procedure Form: Permeable Pavement Systems (PPS)

Sheet 1 of 2

Designer: G. Frazer
Company: BMP Inc.
Date: November 29, 2010
Project: Shops at 56th Ave.
Location: SE corner of 56th Ave. and 83rd St.

1. Type of Permeable Pavement Section A) What type of section of permeable pavement is used? (Based on the land use and activities, proximity to adjacent structures and soil characteristics.)	Choose One: ○ No Infiltration ● Partial Infiltration Section ○ Full Infiltration Section
B) What type of wearing course?	Choose One: ● PICP ○ Concrete Grid Pavement ○ Pervious Concrete ○ Porous Gravel
2. Required Storage Volume A) Effective Imperviousness of Area Tributary to Permeable Pavement, I_a	I_a = 55.0 %
B) Tributary Area's Imperviousness Ratio ($I = I_a / 100$)	I = 0.550
C) Tributary Watershed Area (including area of permeable pavement system)	A_{Trib} = 55,000 sq ft
D) Area of Permeable Pavement System (Minimum recommended permeable pavement area = 13491 sq ft)	A_{PPS} = 15,000 sq ft
E) Impervious Tributary Ratio (Contributing Impervious Area / Permeable Pavement Ratio)	R_T = 1.7
F) Water Quality Capture Volume (WQCV) Based on 12-hour Drain Time ($WQCV = (0.8 * (0.91 * I^3 - 1.19 * I^2 + 0.78 * I) / 12) * Area$)	WQCV = 932 cu ft
G) Is flood control volume being added?	Choose One: ● YES ○ NO — Provide overflow to carry runoff directly into the reservoir layer to ensure use of flood control volume regardless of infiltration rates.
H) Total Volume Needed	V_{Total} = 6,340 cu ft
3. Depth of Reservoir A) Minimum Depth of Reservoir (Minimum recommended depth is 6 inches)	D_{min} = 18.0 inches
B) Is the slope of the reservoir/subgrade interface equal to 0%?	Choose One: ● YES- Flat or Stepped Installation ○ NO- Sloped Installation
C) Porosity (Porous Gravel Pavement ≤ 0.3; Others ≤ 0.40)	P = 0.40
D) Slope of the Base Course/Subgrade Interface	S = _____ 0 ≤ P
E) Length Between Lateral Flow Barriers	L = _____ ft
F) Volume Provided Based on Depth of Base Course Flat or Stepped: $V = P * ((D_{min}-)/12) * Area$ Sloped: $V = P * ((D_{min} - 6*SL-1)) / 12] * Area$	V = 8,500 cu ft
4. Lateral Flow Barriers A) Type of Lateral Flow Barriers	Choose One: ○ Concrete Walls ○ PVC geomembrane installed normal to flow ● N/A- Flat Installation ○ Other (Describe):
B) Number of Permeable Pavement Cells	Cells = 1
5. Perimeter Barrier A) Is a perimeter barrier provided on all sides of the pavement system? (Recommended for PICP, concrete grid pavement, or for any no-infiltration section.)	Choose One: ● YES ○ NO

Design Procedure Form: Permeable Pavement Systems (PPS)

Sheet 2 of 2

Designer: G. Frazer
Company: BMP Inc.
Date: November 29, 2010
Project: Shops at 56th Ave.
Location: SE corner of 56th Ave. and 83rd St.

6. Filter Material and Underdrain System A) Is the underdrain placed below a 6-inch thick layer of CDOT Class C filter material?	Choose One: ● YES ○ NO ○ N/A
B) Diameter of Slotted Pipe (slot dimensions per Table PPs-2)	Choose One: ● 4-inch ○ 6-inch
C) Distance from the Lowest Elevation of the Storage Volume (i.e. the bottom of the base course to the center of the orifice)	y = 3.8 ft
7. Impermeable Geomembrane Liner and Geotextile Separator Fabric A) Is there a minimum 30 mil thick impermeable PVC geomembrane liner on the bottom and sides of the basin, extending up to the top of the base course?	Choose One: ○ YES ● NO
B) CDOT Class B Separator Fabric	Choose One: ○ Placed above the liner ○ Placed above and below the liner
8. Outlet (Assumes each cell has similar area, subgrade slope, and length between lateral barriers (unless subgrade is flat). Calculate cells individually where this varies.) A) Depth of WQCV in the Reservoir (Elevation of the Flood Control Outlet)	D_{WQCV} = 1.86 inches
B) Diameter of Orifice for 12-hour Drain Time (Use a minimum orifice diameter of 3/8-inches)	$D_{Orifice}$ = 0.62 inches

Notes: _____

Permeable Interlocking Concrete Pavement

- **Concrete Grid Pavement – concrete blocks laid together to maintain spaces between blocks to promote runoff entering the pavement.**

- **Site Selection**
  - **Intersections**
  - **Parking lots**
  - **Residential streets**
  - **Emergency vehicle access**
  - **Equipment storage areas**

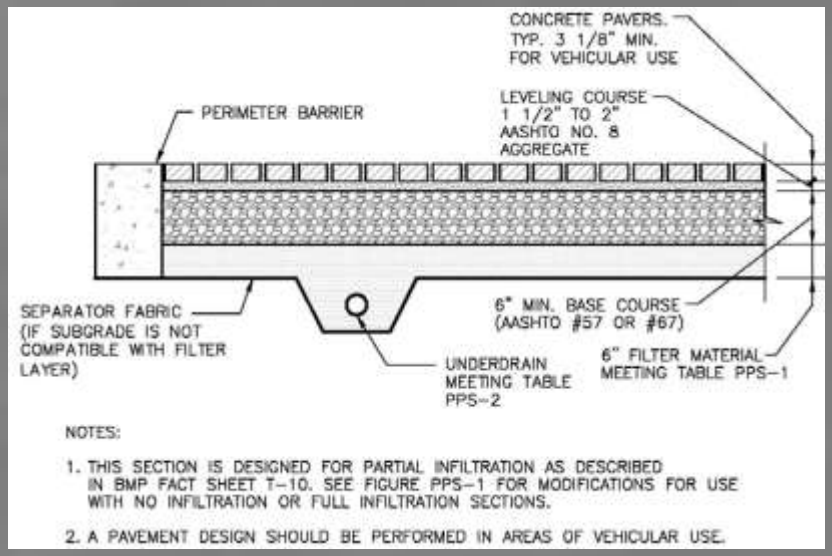


Figure PICP-1. PICP Pavement Section

Permeable Interlocking Concrete Pavement

- **Pavement design**
  - **A herring bone pattern is recommended for areas with vehicular traffic as it provides greater structural support.**
  - **ADA accessible areas should have a maximum spacing of 0.5 inches.**
  - **The perimeter should be lined with concrete.**
  - **Cut pavers must be at least 40% of its original size when exposed to vehicular traffic.**

Permeable Interlocking Concrete Pavement

- **Benefits**
  - **Traffic Calming**
  - **Can be reused if removed for roadwork**
  - **Maintains infiltration rates**
  - **Can be ADA compliant**
  - **Variety of colors and patterns**

Concrete Grid Pavement

- **Concrete Grid Pavement - a pavement consisting of at least 20% large openings filled with free draining material.**
- **Site Selection**
  - **Overflow parking areas**
  - **Maintenance roads**
  - **Emergency vehicle access**
  - **Equipment storage areas**

- **Installation of a stable perimeter (concrete, asphalt, etc) is recommended to limit movement and grinding of blocks.**

Pervious Concrete

- **Pervious Concrete - a penetrable concrete mixture with limited amounts of sand to create a considerable amount of voids and promote infiltration.**

- **Site Selection**
  - **Low volume areas with low vehicular speeds**
  - **Parking Lots**
  - **Streets and alleys**
  - **Sidewalks/Plazas**
  - **Tennis Courts**

Benefits

- Meets ADA requirements.
- Maintains high infiltration rates.

Limitations

- When the pavement starts to ravel, a patch is needed quickly to limit the area of the damage.
- Limited success in Colorado to date.
- Shorter life span than conventional concrete as well as other permeable pavements in this manual.
- Quality control during installation is critical to the success of the pavement.
- A long cure time limits use of the area following construction.

Pervious Concrete

- **Joints should be provided with expansion material at a maximum of 20' spacing to allow for surface expansion and contraction.**
- **Typical infiltration rates are on the order of 480 in./hr.**

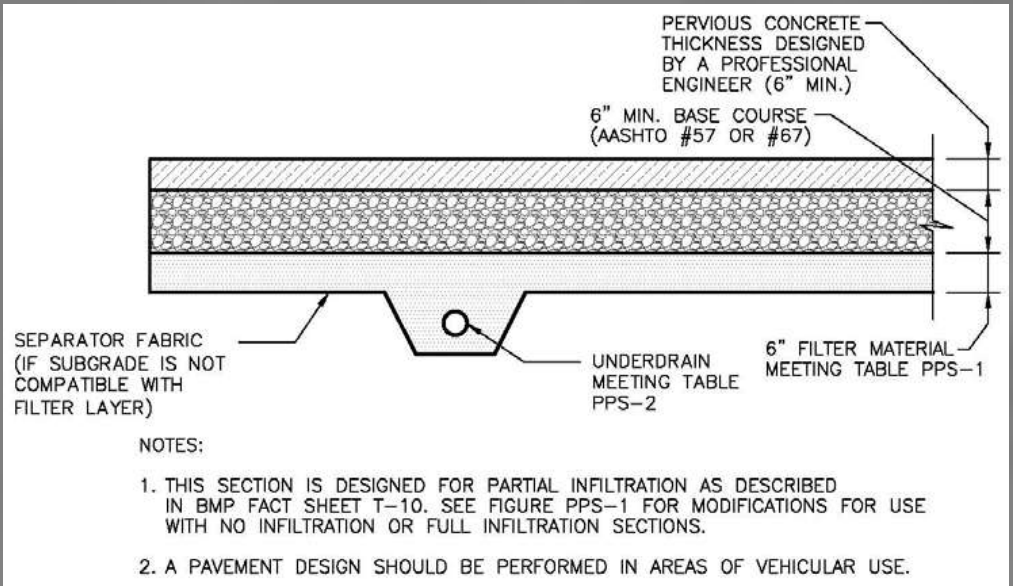


Figure PC-1. Pervious Concrete Pavement Section

Porous Gravel

- **Porous gravel can be used as an alternative to ordinary gravel.**

- **Characteristics**
  - **Low cost**
  - **Not ADA compliant**
  - **Ruts without stabilization**

- **Site Selection**
  - **Parking lots**
  - **Driveways**
  - **Storage yards**
  - **Maintenance roads**

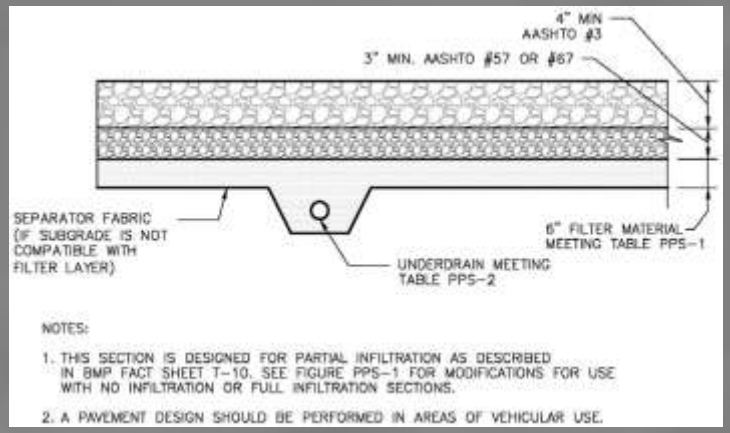


Figure PG-1. Porous Gravel Pavement Section

Reinforced Grass

- **Reinforced Grass - designed to have the stability of pavement and the appearance of grass.**

- **Price and stability can vary between products and product lines.**

- **Site Selection**
  - **Roadway shoulder**
  - **Maintenance roads**
  - **Emergency Vehicle access**
  - **Infrequently used parking areas**

Benefits

- Low cost compared to other permeable pavements.

Limitations

- Not ADA compliant.
- Ruts without stabilization.

Reinforced Grass

- **The most commonly used systems are Plastic Cellular Paving and Concrete Cellular Paving.**
  - **Plastic Cellular Paving**
    - **Interlocking plastic pavers with a High percentage of grass surface**
  - **Concrete Cellular Paving**
    - **Interlocking concrete pavers or cast in place**

- **Product considerations**
  - **Frequency of use**
  - **Appearance**
  - **Vehicle Loading**
  - **Irrigation Expectations**
  - **Drainage Capability**

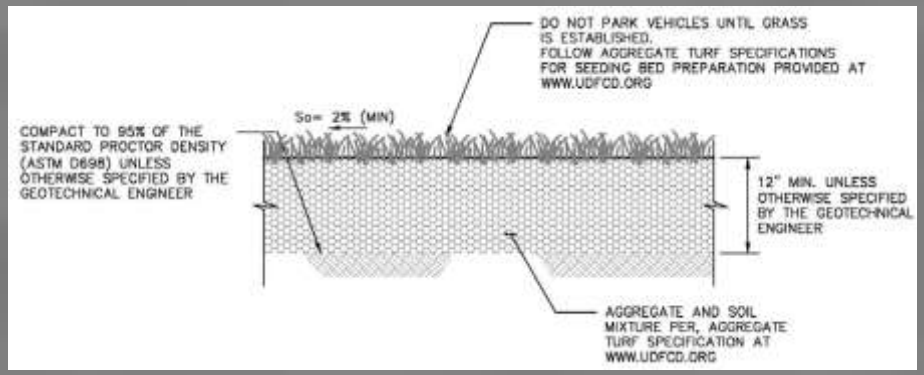


Figure RG-1. Aggregate Turf Pavement Section

Supplemental References

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Questions?

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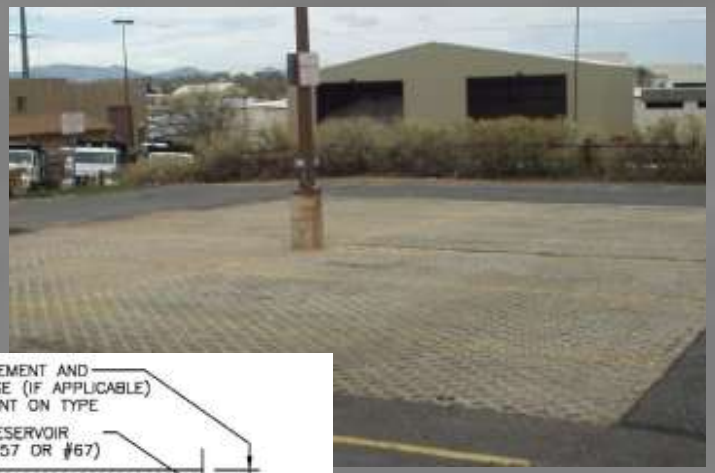

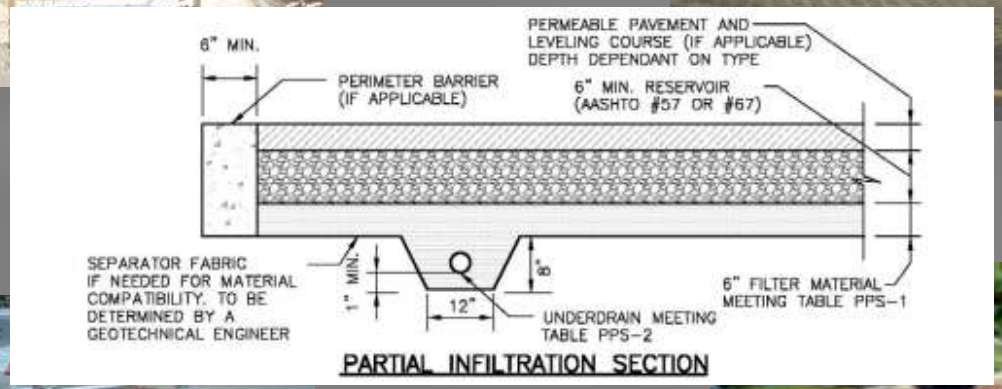

The Philly Story Video

[redacted] – AECOM

- Bio Swale
- Rain Garden
- Soil Augmentation
- Wetlands and Green Roofs

Bioretention Design Standards

- Drainage area for bioretention areas shall not exceed 2 acres. One acre is preferred.
- Design bioretention areas to draw down within 48 hours after a storm event.
- 25 feet from buildings with basements and 10 feet from buildings without basements.
- Provide an overflow structure or outlet to convey flow from storms that are not treated by the bioretention facility.
- The discharge pipe should not be less than 4 inches.
- A slide gate or valve must be placed on the upstream side of the discharge pipe to regulate flow and provide access for clean out.
- All inlets must be designed with a sediment basin and trash rack.

Bio Swale

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NOTES:

1. ALL BIORETENTION FACILITIES SHALL HAVE A MINIMUM 20 FOOT ACCESS EASEMENT CONNECTING TO A DEDICATED PUBLIC RIGHT OF WAY. ACCESS ROAD SHALL HAVE MIN. 12' STABILIZED WIDTH, MAX. LONG. GRADE OF 15%, MAX. CROSS-SLOPE 5%.

2. ALL DRAINAGE AREAS TO A BIORETENTION FACILITY ARE TO BE STABILIZED PRIOR TO INSTALLATION OF AMENDED SOILS, MULCH OR PLANTINGS.

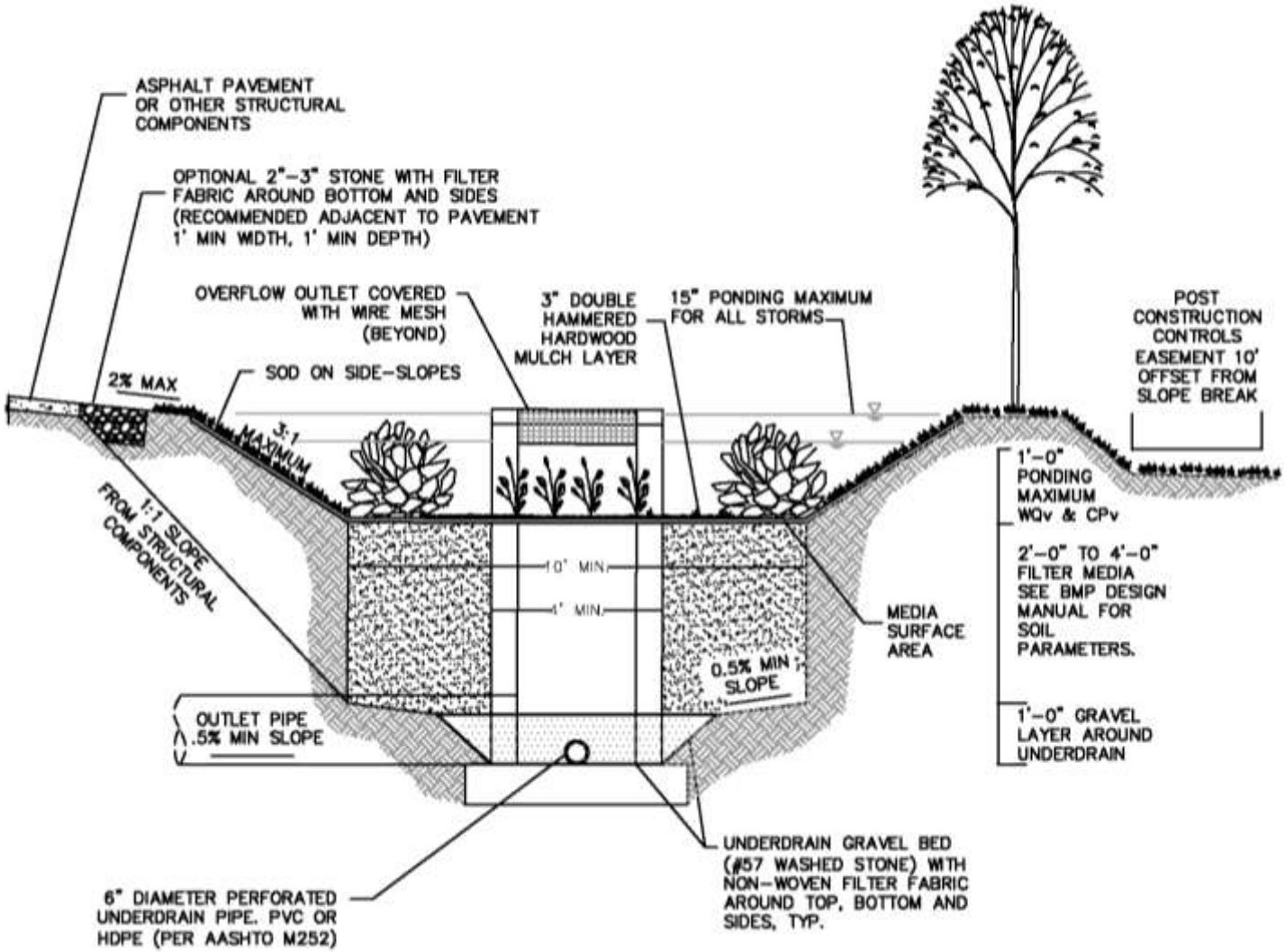
3. AMENDED SOIL WILL ONLY BE PERMITTED WITH A VALID SOIL ANALYSIS REPORT. NO AMENDED SOIL SHALL BE ALLOWED ON THE SIDE SLOPES.

4. INSTALL WIRE SCREENING AROUND ALL OUTLET OPENINGS TO PREVENT LOSS OF MULCH.

5. PVC UNDERDRAIN PIPE SHOULD HAVE 3/8" PERFORATIONS SPACED AT 6" CENTERS, MIN. 4 HOLES PER ROW. MAX SPACING OF UNDERDRAIN PIPE IS 10 FEET ON CENTER. HDPE SHALL ADHERE TO AASHTO M252 SPECS.

6. UNDERDRAIN CLEANOUTS SHOULD EXTEND A MIN. OF 6" ABOVE TOP SURFACE OF MULCH LAYER. CLEANOUTS MAY BE FLUSH WITH TOP OF SURFACE TO ALLOW DRAWDOWN.

7. ONLY SMALL MATURING TREES ARE ALLOWED TO BE PLANTED IN THE AMENDED SOILS.

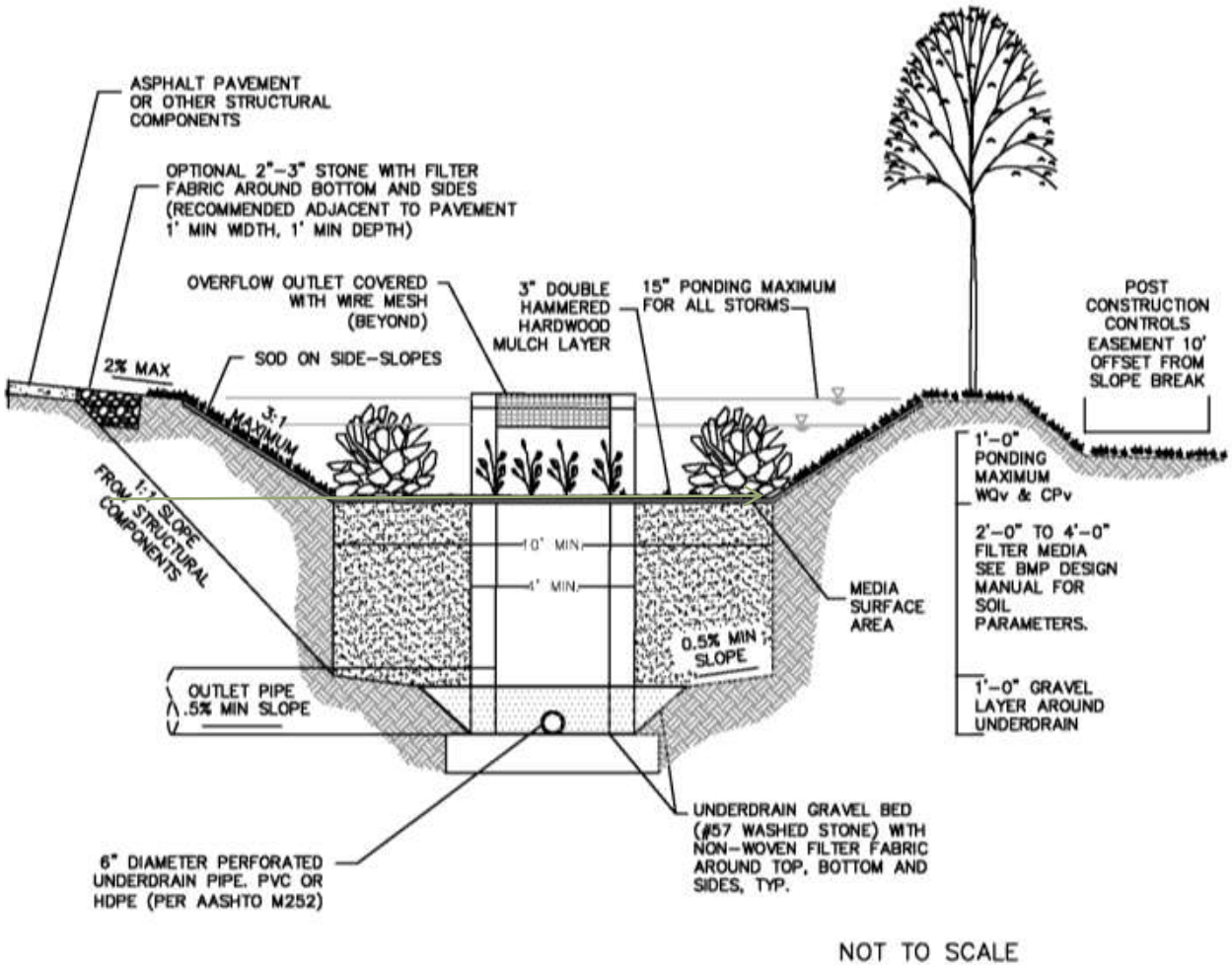


NOT TO SCALE

Bioretention Pollutant Removal

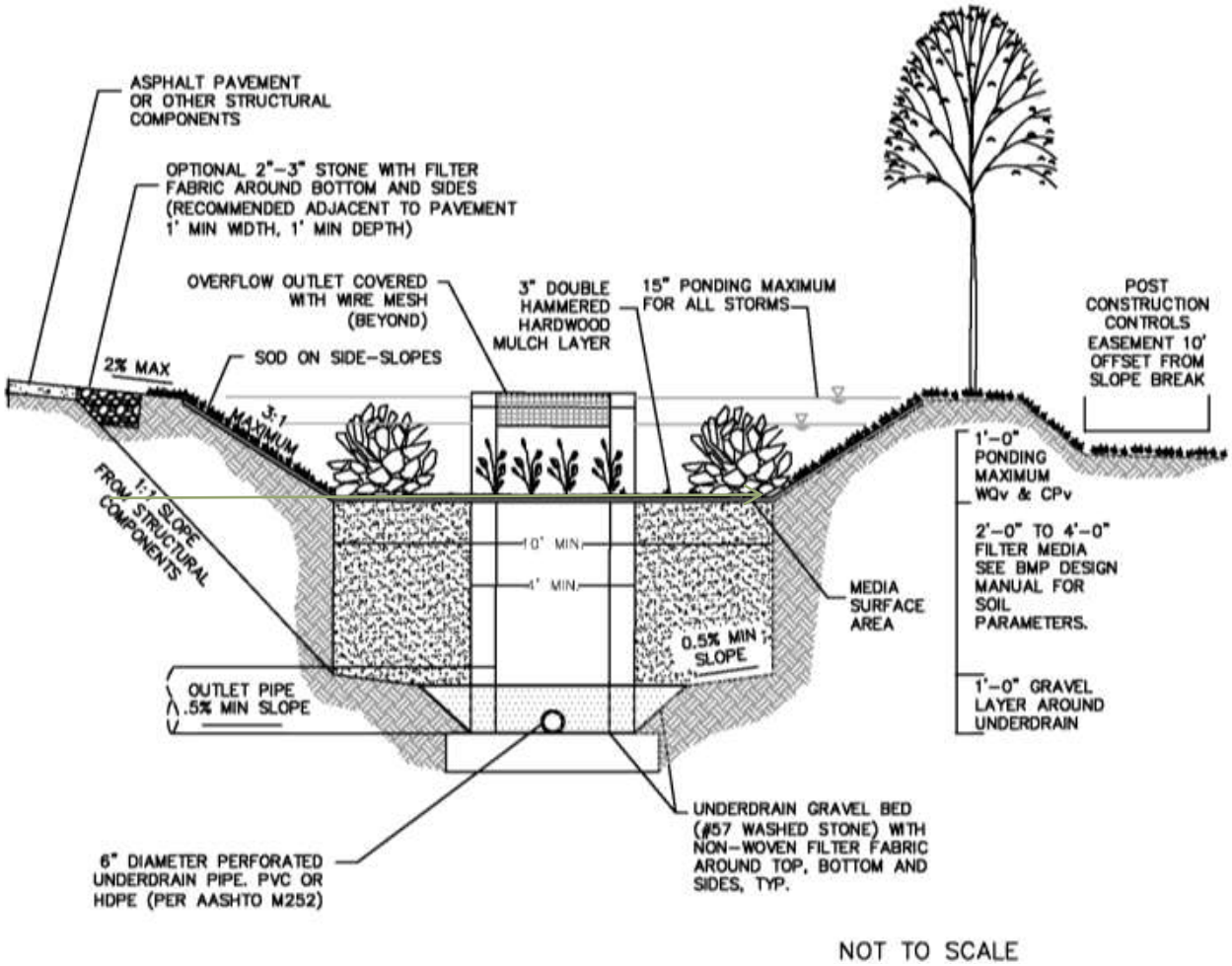
- **<u>Pollutant Removal</u>**
- **Copper 43%–97%**
- **Lead 70%–95%**
- **Zinc 64%–95%**
- **Phosphorus 65%–87%**
- **Total Kjeldahl nitrogen (TKN) 52%–67%**
- **Ammonium (NH_4^+) 92%**
- **Nitrate (NO_3^-)15%–16%**
- **Total nitrogen (TN) 49%**
- **Calcium 27%**

Bio Swale - Calculations



Bio Swale - Calculations

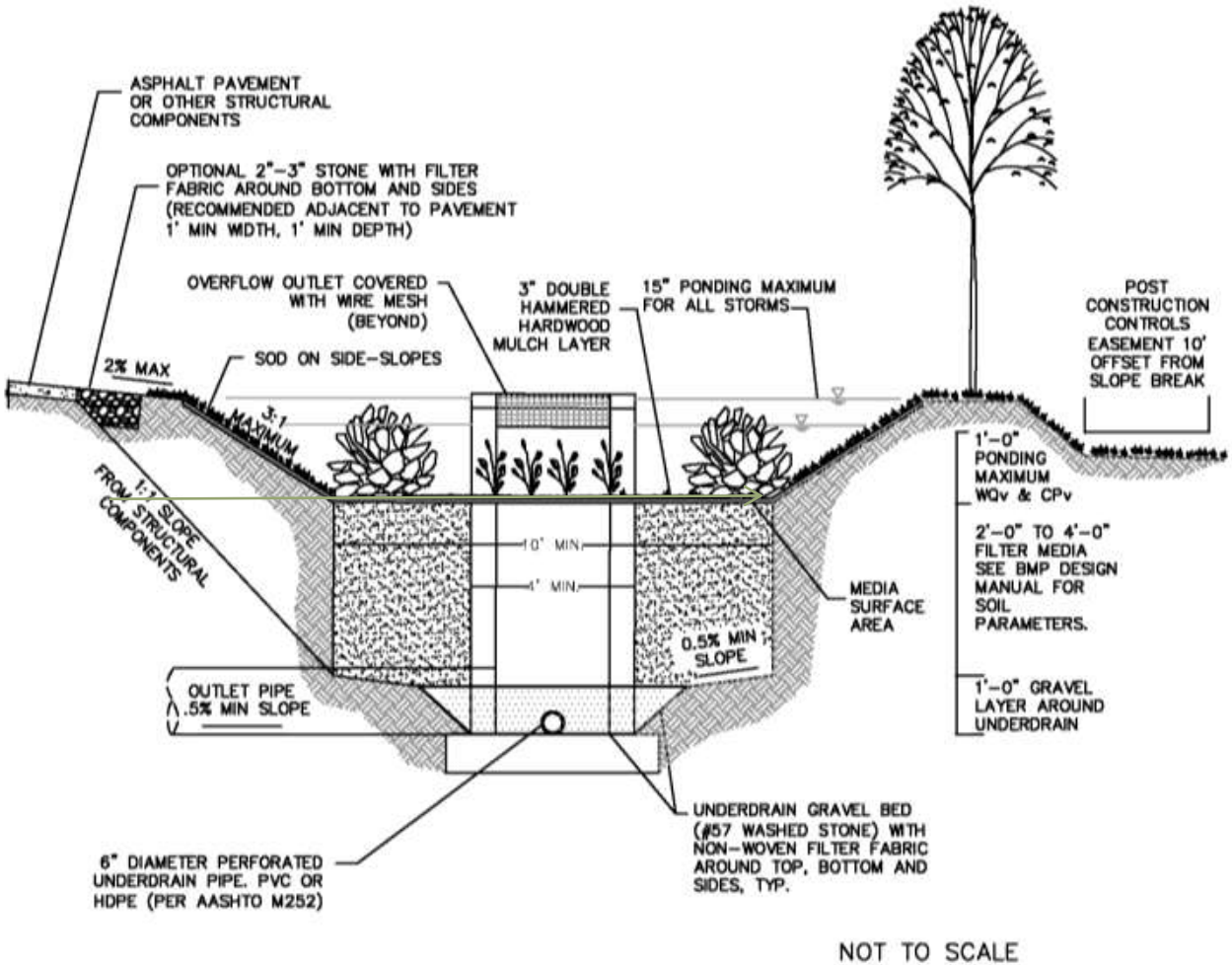
Volume of pond
L X W X H = Ft3



Bio Swale - Calculations

Volume of pond
L X W X H = Ft3

Volume of amended soil
L X W X H X 25% = Ft 3

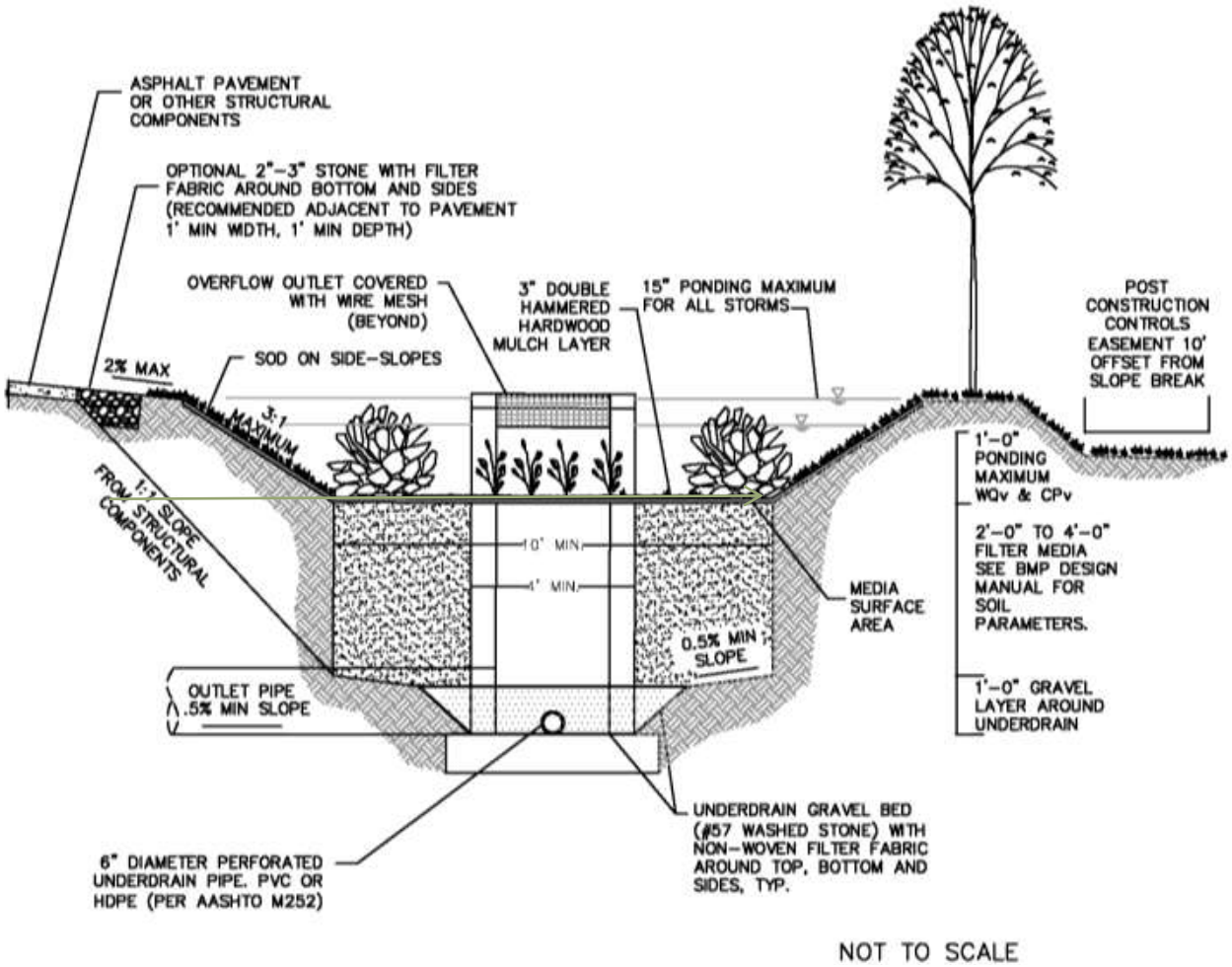


Bio Swale - Calculations

Volume of pond
L X W X H = Ft3

Volume of amended soil
L X W X H X 25% = Ft 3

Vol of Filter Media
L X W X H X 30% = Ft 3



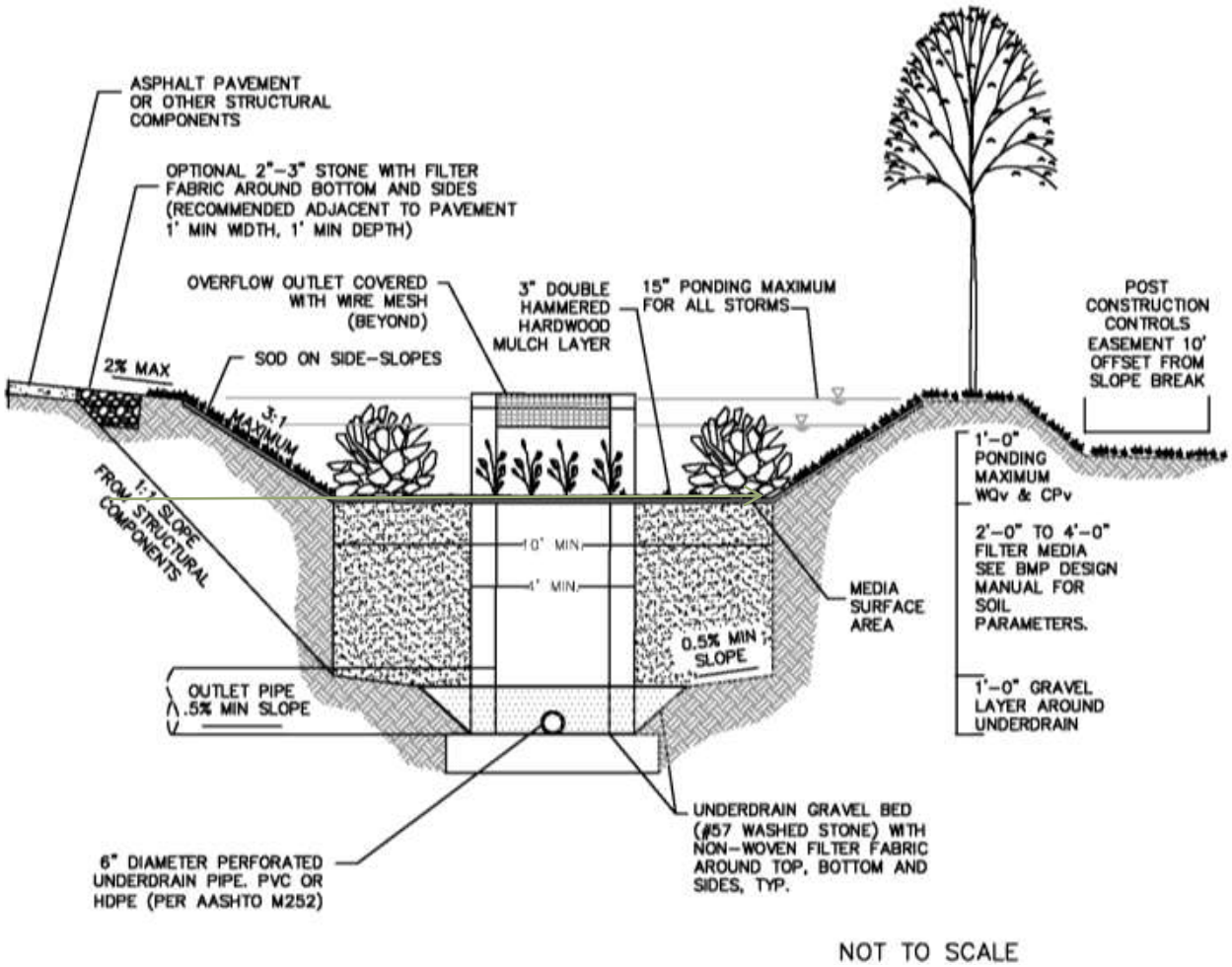
Bio Swale - Calculations

Volume of pond
L X W X H = Ft3

Volume of amended soil
L X W X H X 25% = Ft 3

Vol of Filter Media
L X W X H X 30% = Ft 3

Vol of Gravel Layer
L X W X H X 20% = Ft 3



Bio Swale - Calculations

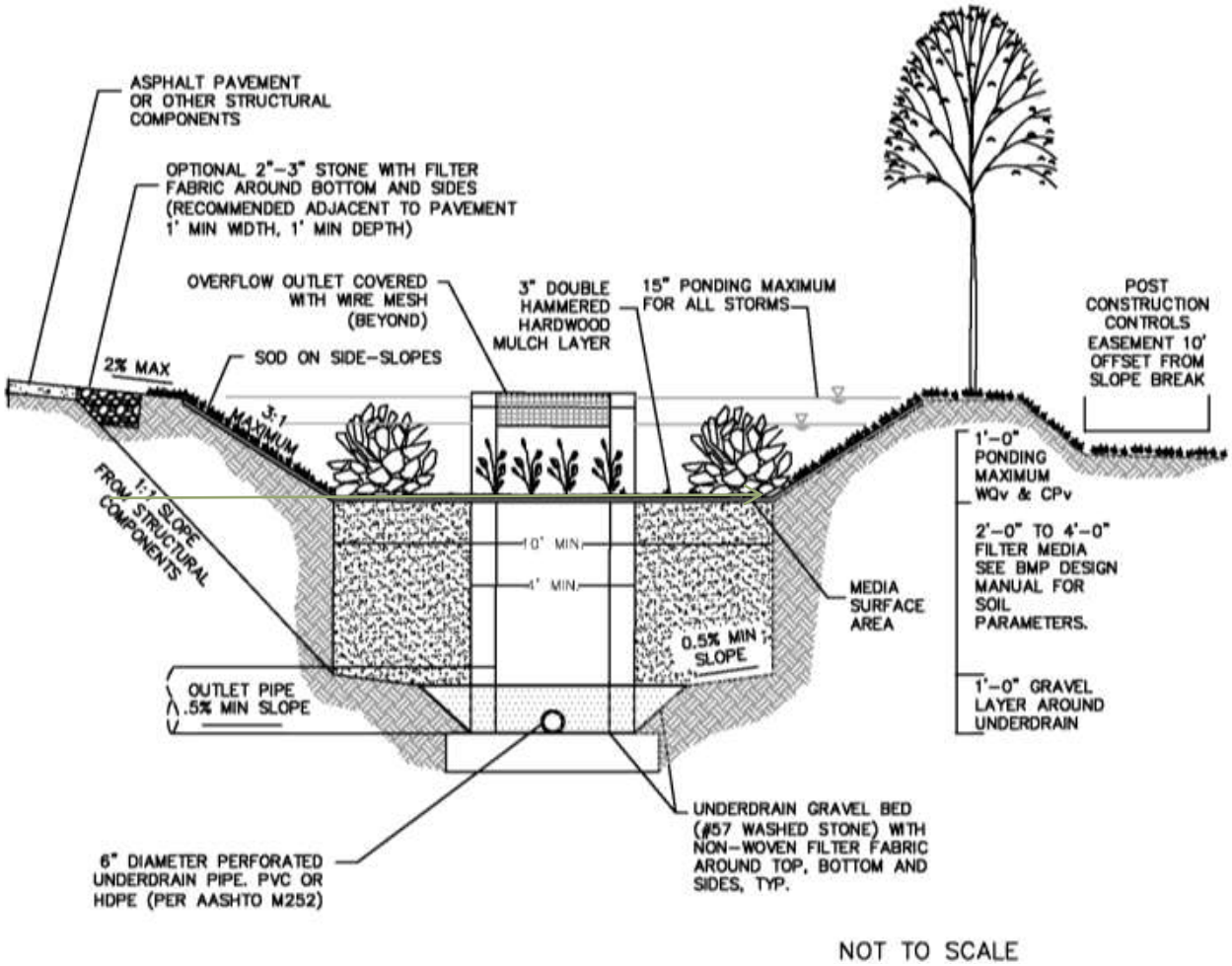
Volume of pond
L X W X H = Ft3

Volume of amended soil
L X W X H X 25% = Ft 3

Vol of Filter Media
L X W X H X 30% = Ft 3

Vol of Gravel Layer
L X W X H X 20% = Ft 3

Total Volume
Pond + Amended + Filter Media + Gravel



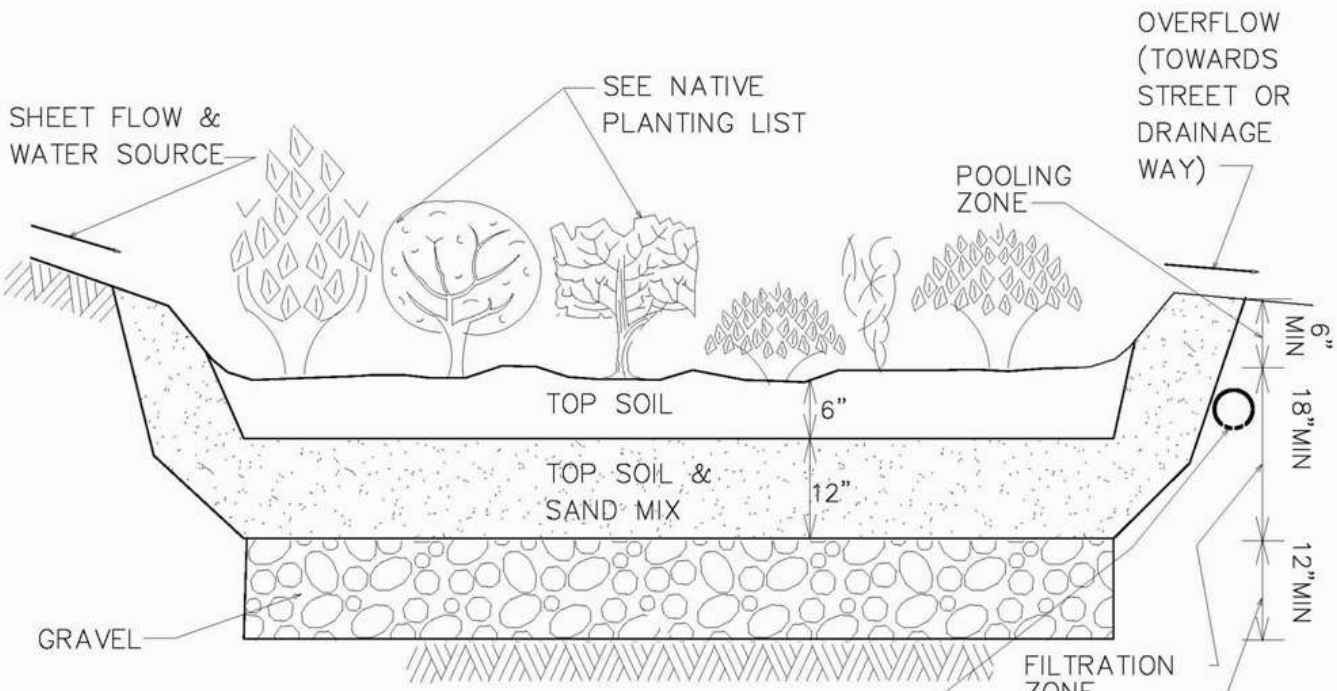
Bioretention Maintenance Activities

Activity	Schedule
Re-mulch void areas. Mow turf areas. Treat diseased trees and shrubs.	As needed
Water plants daily for 2 weeks	At project completion
Inspect soil and repair eroded areas. Remove litter and debris.	Monthly
Remove and replace dead and diseased vegetation.	Twice per year
Add mulch. Replace tree stakes and wires.	Once per year

Operations and Maintenance

- Ease of access
- Settling forbay
- Minimum sized outlet structure to use as a washout
- Grate over outlet
- Reverse siphon
- Outlet protection

Rain Garden



Rain Garden

Rain Garden Maintenance Activities

- **The rain garden should be inspected for signs of erosion or bare soils, sediment, and debris. Particular attention should be paid to areas adjacent to buildings or homes to ensure resources are protected. Accompanying infrastructure such as a downspout connection, pretreatment buffer strip, or overflow structures should be inspected regularly for structural integrity and proper function**

Wetlands and Green Roofs

- **Wetland**
  - **Must stay out of the drainage way to avoid 404 permit issues**
  - **Must remain saturated 3 months out of the year**
  - **Requires certain soil types and vegetation species**
- **Green Roofs**
  - **In Colorado they need to be irrigated**
  - **Difficult to sustain**
  - **Additional structural requirements**
  - **Expensive**

Soil Amendments and BMPs

- Less expensive then replacing in-situ soils with soil mix
- Improves ecological functions and sponge capacity of the soil
- "Rule of Thumb" Mix 1/3 compost with native soil
- Tailored to vegetation and site
- Plan on 18 inches of growth media
- Can be increased to create more storage

Soil Types

- **Fort Carson mainly composed of C and D soils**
  - **Require compost/organics and/or sand for growing media**
  - **Proper use of under drains**
    - **Perforations not critical – just exceed capacity of under drain**
    - **Include standpipe/clean-out/observation port**
    - **PVC can be used**

Engineered Soil Mix

- **Provides good infiltration even when compacted to 85-90%**
- **Design infiltration rate = 1 to 2 inches/hr**
- **65 to 70% gravelly sand and 30-35 Compost for storage media**

Austin, Tx
Biofiltration Blend

- **Porosity n less then 0.45**
- **Saturated hydraulic Conductivity k> 2 inches per hour**
- **Percent Organic Matter by weight =1-4%**
- **Cation Exchange Capacity CEC > 10mg/100 grams**

Austing, Tx
Biofiltration Blend

- **Particle size distribution**
  - **70-90 % Sand**
  - **2-10% clay**
  - **Silt plus Clay < 25%**

Composting on Post

Questions

[redacted] – AECOM

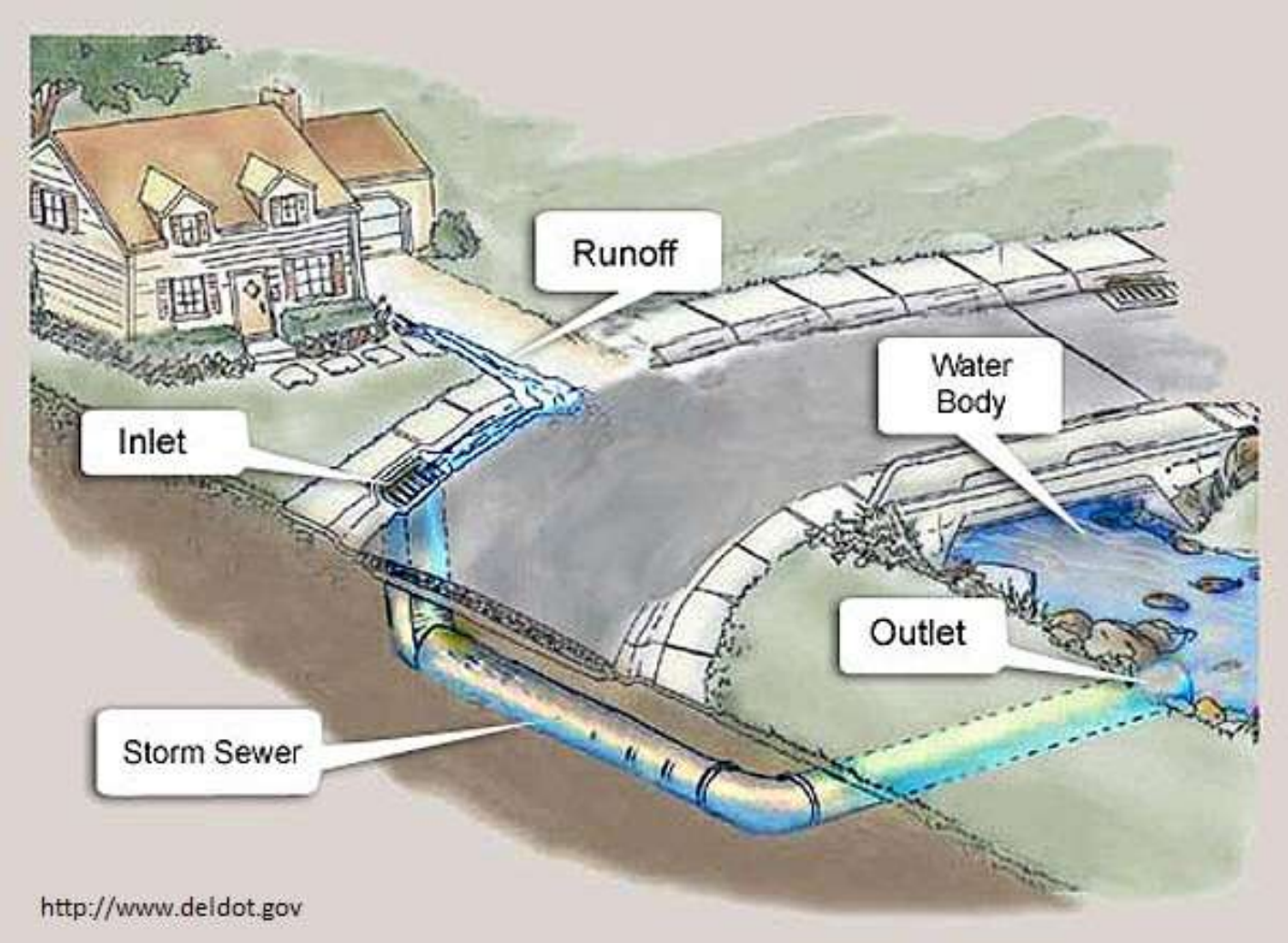
- Disconnect impervious areas
- Tree Box
- Planters

Directly Connected Impervious Area (DCIA)

- **Impervious area that drains directly to the improved drainage system (e.g. paved gutter) and subsequently to the storm sewer**

Directly Connected Impervious Area (DCIA)

Directly Connected Impervious Area (DCIA)



Directly Connected Impervious Area (DCIA)

Hydrologic impacts of DCIA

- **Minimal infiltration**
- **Greater runoff volume**
- **Greater runoff velocity**
- **Shortened time of concentration**
- **Increased pollutants**

Minimizing DCIA

- **Creating a pervious break between the impervious source area and the delivery system**

Minimizing DCIA

http://www.gcbl.org/blog/marc-lefkowitz/will-our-stormwater-program-count-small-acts-green

http://www.gcbl.org/blog/marc-lefkowitz/will-our-stormwater-program-count-small-acts-green

Minimizing DCIA

Minimizing DCIA

Examples:

- **Rooftop disconnection**
- **Pavement disconnection**
- **Curb cuts**
- **Porous pavements**
- **Planter boxes**
- **Tree filter boxes**

Minimizing DCIA

Examples/Strategies:

- **Interrupting continuous flow paths**
- **Encouraging sheet flow through vegetated areas**
- **Strategically locating impervious areas in design phase**

Minimizing DCIA

Benefits:

- **Encourage infiltration**
- **Slow flow velocity**
- **Delay time of concentration**
- **Filter pollutants**

Minimizing DCIA

Other considerations:

- **Stabilized and suitable pervious areas**
- **Suitable soils**
- **Maintenance/clean out**
- **Overflow/outlet**
- **Pollutant reductions**

Planter Box

http://www.epa.gov/owow/NPS/lid/section438/pdf/final_sec438_eisa.pdf

Planter Box

AUG 17 2001
http://www.lowimpactdevelopment.org/ffxcty/6-2_planterbox_draft.pdf

Planter Box

Stormwater planter box
Photo Credit: Pennsylvania Horticultural Society

http://www.csc.temple.edu/t-vssi/BMPSurvey/waterview.htm

Planting box
Photo Credit: Pennsylvania Horticultural Society
http://www.csc.temple.edu/t-vssi/BMPSurvey/waterview.htm

Planter Box

Different Types:

- **Contained**
- **Infiltration**
- **Flow-through**

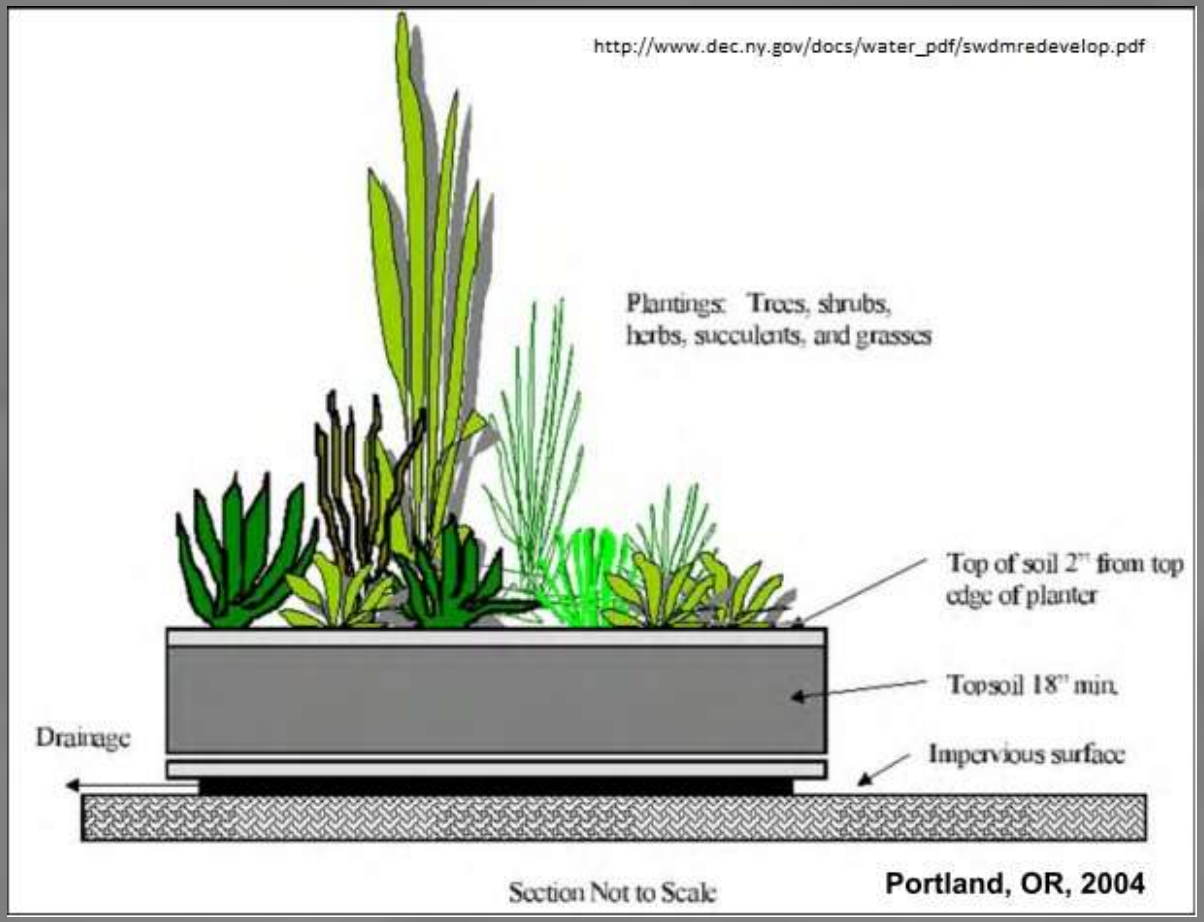
Planter Box

Contained Planter Box

- **Simple – potted plant within a container**
- **Overflow when full**

Planter Box

Contained Planter Box



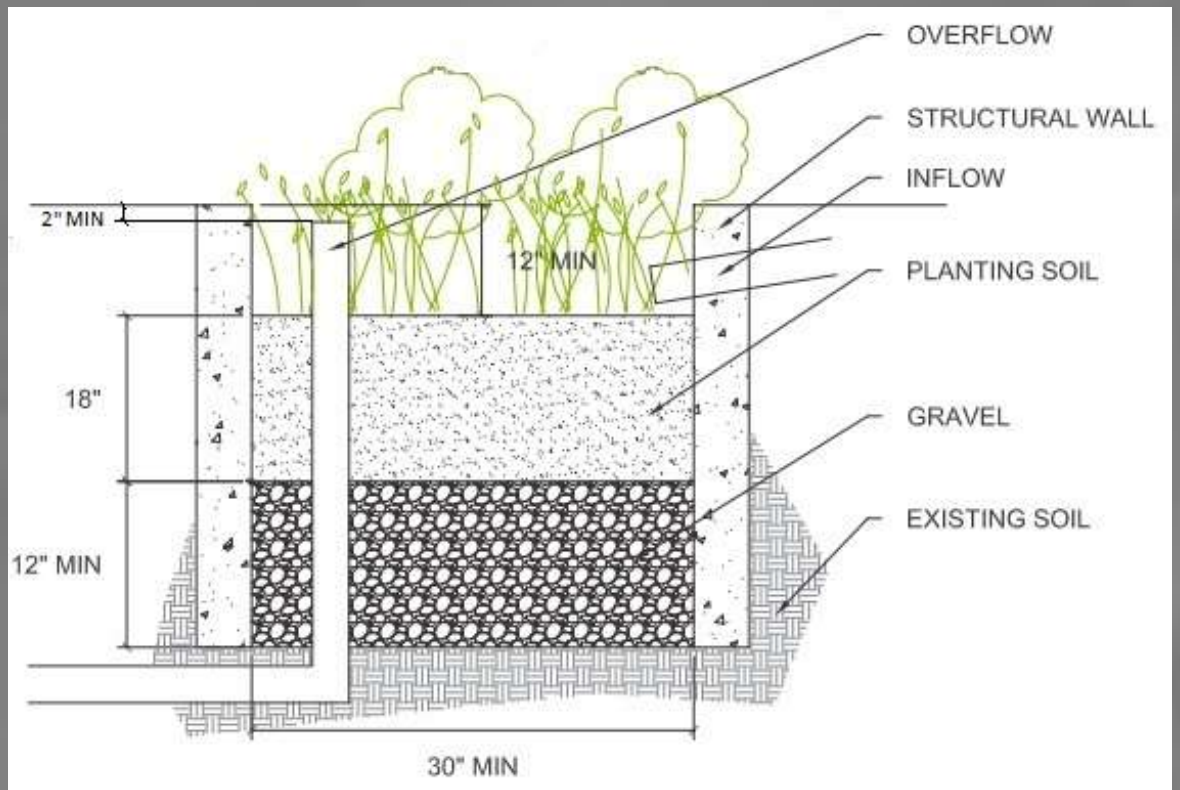
Planter Box

Infiltration Planter Box

- **Filters rooftop runoff through soil media**
- **Opening to ground on bottom of box to infiltrate captured water**

Planter Box

Infiltration Planter Box



Charles River Watershed Association, 2008

Adapted from:
Portland: Stormwater Management Manual (Adopted July 1, 19999, Revised September 1, 2004)
http://www.portlandonline.com/bes/index.cfm?c=dfbbh Accessed 01/29/2008

Note: Dimensions are typical, always verify local conditions before installation

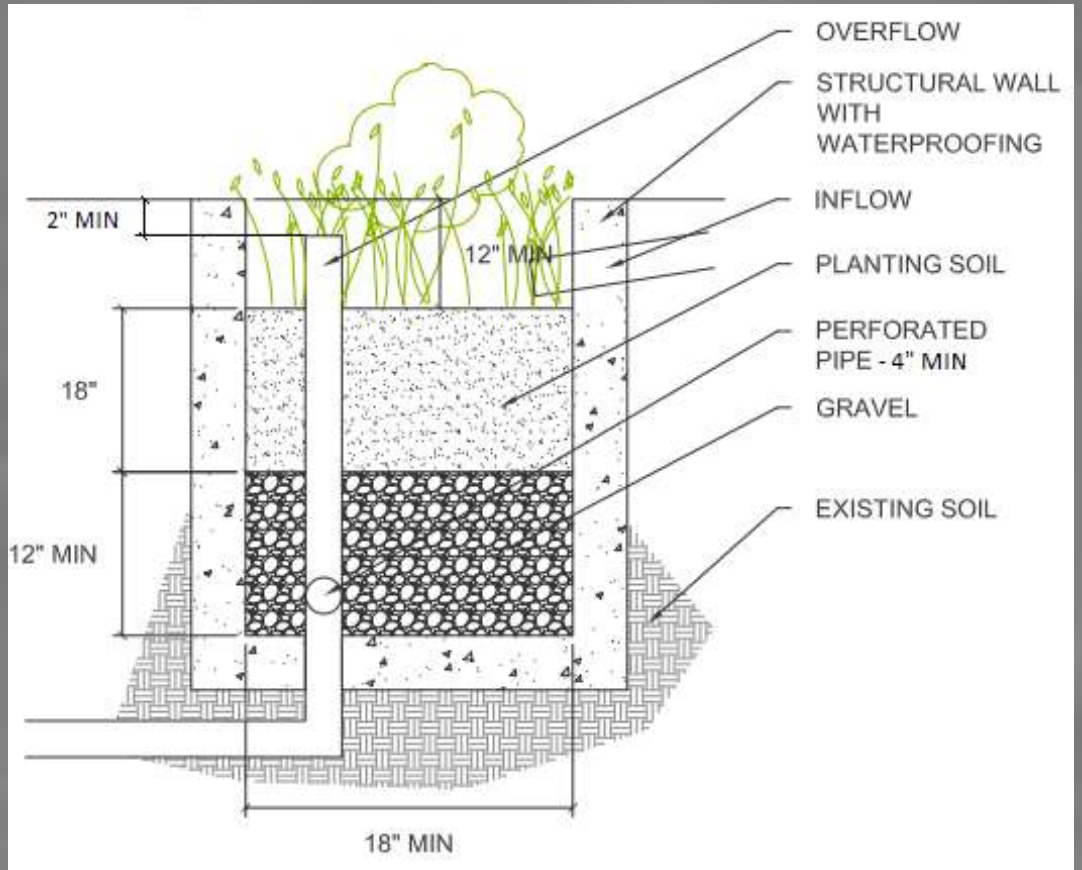
Planter Box

Flow-through Planter Box

- **Filters rooftop runoff through soil media**
- **Impermeably lined bottom with outflow pipe to discharge to drainage system**

Planter Box

Flow-through Planter Box



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http://www.portlandonline.com/bes/index.cfm?c=dfbbh Accessed 01/29/2008

Note: Dimensions are typical, always verify local conditions before installation

Planter Box

Advantages:

- **Small size**
  - **Easily integrated into site design**
  - **Appropriate for highly urbanized areas**
  - **Establish pervious areas within plazas, courtyards, streets, etc.**
  - **Easily integrated into multiple BMP treatment trains**

- **Aesthetic appeal**

Planter Box

Advantages:

- **Flexible:**
  - **Can aid in infiltration (infiltration type)**
  - **Can be placed immediately adjacent to buildings (flow-through type)**
  - **Provide LID treatment where infiltration not appropriate such as poor soils or SWMUs (flow-through type)**
- **Good for demonstration projects**

Planter Box

Advantages:

- **Hydrologic Benefits**
  - **Volume**
  - **Rate**
- **Water Quality Benefits**
  - **Able to treat common rooftop pollutants e.g. sediment, dust, bacteria**
  - **Able to treat other pollutants such as nitrogen, phosphorus, metals, oil and grease if exposed to them**
  - **Temperature reduction**

Planter Box

Water Quality Benefits (Bioretention area)

- **Planter box performance expected to be less than bioretention area**

Pollutant	Pollutant Removal
Copper	43%–97%
Lead	70%–95%
Zinc	64%–95%
Phosphorus	65%–87%
Total Kjeldahl nitrogen (TKN)	52%–67%
Ammonium (NH_4^+)	92%
Nitrate (NO_3^-)	15%–16%
Total nitrogen (TN)	49%
Calcium	27%

Data from Fort Carson BMP O&M Plan, 2011

Planter Box

Disadvantages:

- **Small size**
  - **Only able to treat small area and associated pollutants**
  - **Many planters may be necessary to have significant impact on watershed scale**
- **Watering may be necessary to sustain plant life during dry weather periods**

Planter Box

Design:

Freeboard

- **2” min**

Ponding Reservoir

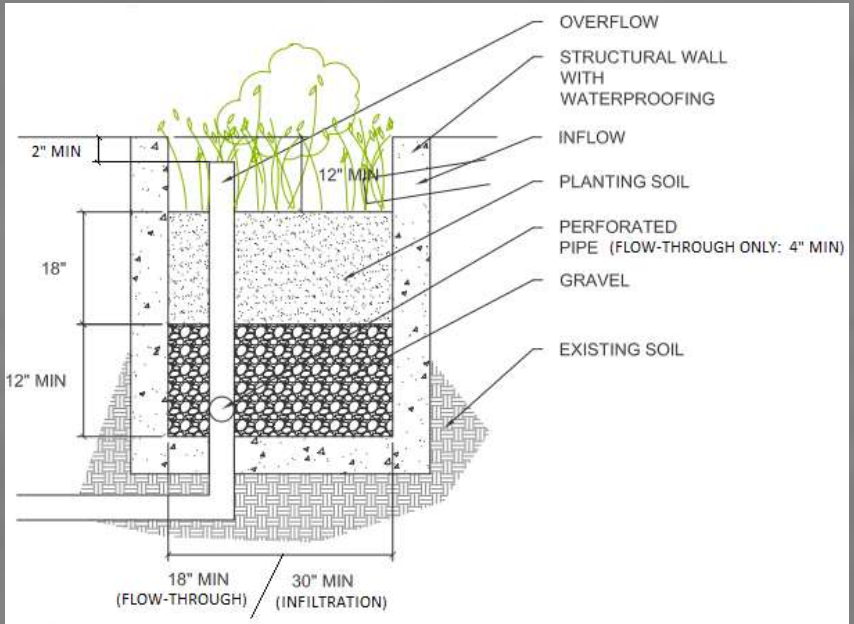
- **12” min**

Growing Media

- **18” min depth**
- **Min infiltration rate 2 in/hr**

Drainage Layer

- **12” min depth**
- **Min infiltration rate 5 in/hr**



Charles River Watershed Association, 2008

Adapted from:
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http://www.portlandonline.com/bes/index.cfm?c=dfbbh Accessed 01/29/2008

Planter Box

Design:

Perforated Underdrain Pipe:

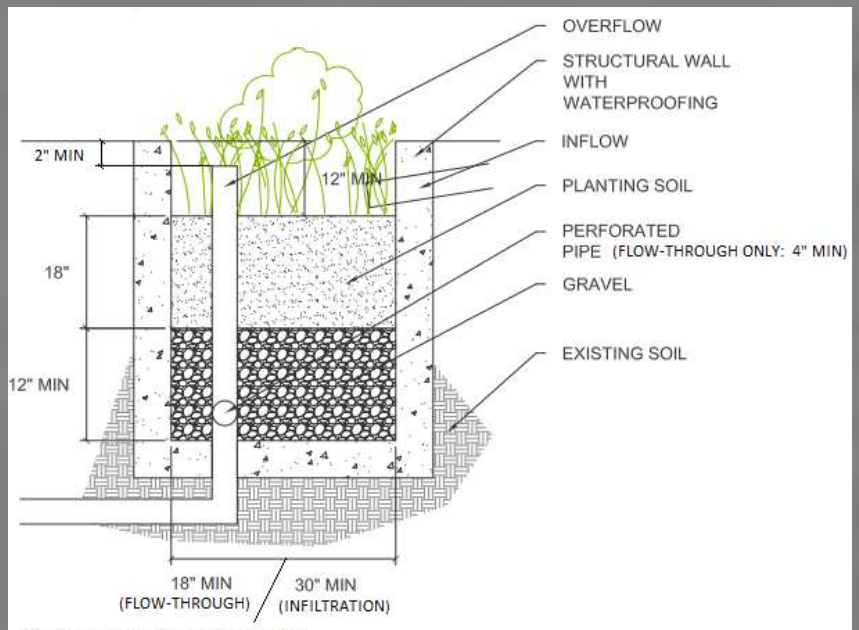
- **4” diameter min**
- **Flow-through only**
- **Monitoring well for maintenance inspections**

Planter Width:

- **18” min flow-through**
- **30” min infiltration**

Planter Length:

- **Based off capture volume requirements…**



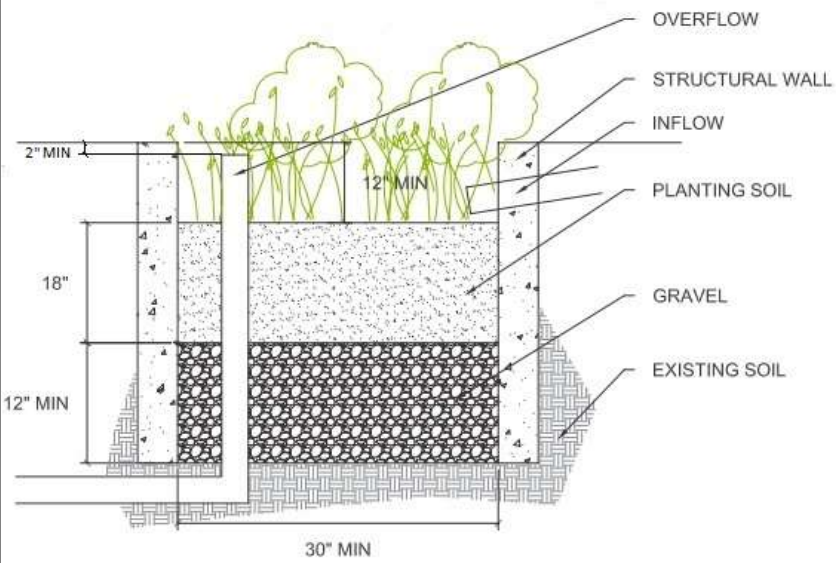
Charles River Watershed Association, 2008

Adapted from:
Portland: Stormwater Management Manual (Adopted July 1, 19999, Revised September 1, 2004)
http://www.portlandonline.com/bes/index.cfm?c=dfbbh Accessed 01/29/2008

Planter Box

Infiltration Design:

- **3' min depth from bottom of planter box to impermeable boundary/seasonably high GW table**
- **2 in/hr min infiltration rate for natural, underlying soils**
- **10' min distance from building foundation**



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http://www.portlandonline.com/bes/index.cfm?c=dfbbh Accessed 01/29/2008

Planter Box

Other Design Considerations:

Treatment areas:

- **No greater than 15,000 sq ft of impervious area**

Ponding time:

- **No greater than 12 hours within planter**

Vegetation:

- **Typically native, hydrophilic flowers, grasses, shrubs and trees**

Downspout:

- **Install “splash rocks” to dissipate energy of incoming water and protect vegetation**

Planter Box

Other Design Considerations:

Overflow:

- **Essential to safely pass flows from large rain events**
- **Protect planter box**
- **Outlet to stabilized area**
  - **NOT sidewalk – avoid ice formation**
  - **Protected vegetated area preferred**

Maintenance Access

Planter Box

Flow-through Example:

This method based off Darcy's Law which governs flow through a porous medium (New York State Stormwater Management Design Manual, 2007)

$$A_f = \frac{V_c \times d}{k \times t \times (h+d)}$$

Where:

A_f = Required surface area of planter box (sq. ft)

V_c = Runoff capture volume (cubic ft)

d = depth of the soil medium (ft) – 1.5 ft min. recommended

k = hydraulic conductivity (ft/day) – 4ft/day is common, but actual values will vary

t = design time to filter treatment volume through filter media (days) – typically 3-4 hrs (0.125 – 0.167 days)

h = average height of water above planter bed (ft) - 1ft max

Planter Box

Maintenance:

- **Vegetation:**

  Remove weeds, replace soil, replace vegetation, water during periods of drought

- **Structural components:**

  Inspect inlets, outlets, underdrains, planter structure and other components for integrity and function. Clean out when necessary

- **Soils:**

  Verify infiltration rates

Planter Box

Maintenance Schedule:

- **1st 6 months of operation:**

  Rainfall events > 0.5 inches or twice in 6 months

- **There after:**

  Rainfall events > 1 year event (1.7 inches for Fort Carson) or annually

- **Replacement:**

  May be necessary after 25 years of operation

Planter Box

AECOM

Cost Considerations:

- **Installation:**

  Approx. $16 - $36/ sq ft planter for new project[1]

  Approx. $33/sq ft planter for redevelopment project[2]

  $8,000 - $18,000 for 500 sq ft planter

- **Maintenance:**

  Approx $400 – $500 for 500 sq ft planter/year[3]

  ($80 - $100/ sq ft planter/year)

1 – Center for Watershed Protection, 2007

2 – New York State Stormwater Management Design Manual, 2007

3 – Charles River Watershed Association, 2008

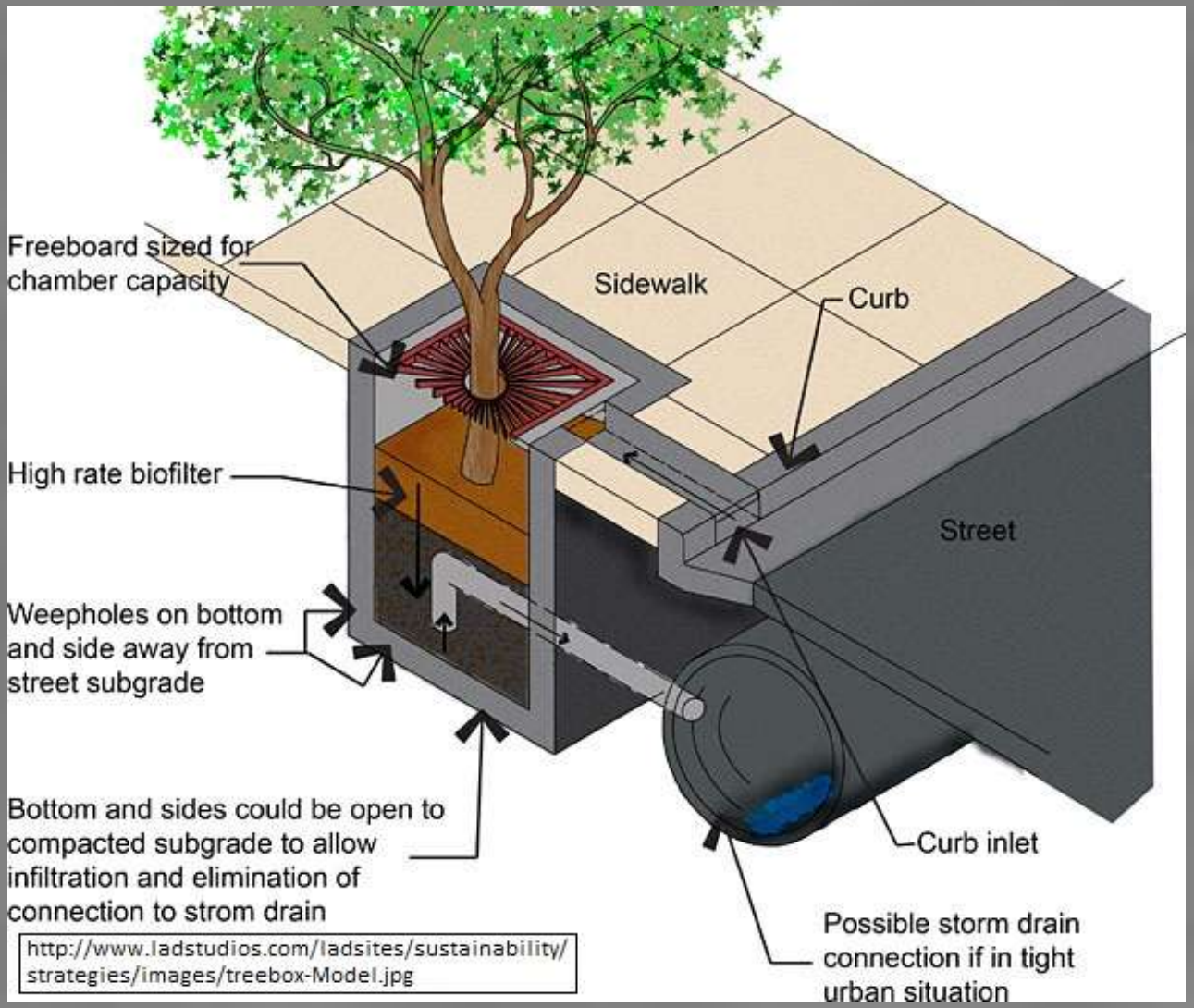
Tree Box Filter

Tree Box Filter

What is it?

- **A tree box filter is a bioretention facility for urbanized areas that typically integrates a tree or shrub, a filtering soil composite matrix, and a storm drain inlet.**

Tree Box Filter



http://www.ladstudios.com/ladsites/sustainability/strategies/images/treebox-Model.jpg

Tree Box Filter

How it Works – Filterra Example:

http://www.filterra.com/media-2009/filterra.html

Tree Box Filter

Different Types:

- **Infiltration:**

  Filters runoff through engineered soil matrix, infiltrates into native, underlying soil

- **Flow Through:**

  Filters runoff through engineered soil matrix, discharges into storm sewer, surface conveyance, or other treatment BMP (underground storage tank, infiltration system, etc.)

Tree Box Filter

Different Types:

- **Various proprietary designs and variations:**

http://www.treeboxfilter.com/design.htm

http://www.filterra.com/

Tree Box Filter

Advantages:

- **Good for new or redevelopment**
- **Easily integrated into urban landscape or other space limited areas**
- **Good for use with other LID treatments**
- **Flexible options:**
  - **Can recharge groundwater and reduce runoff volumes with infiltration types**
  - **Can direct treated flows through other devices if infiltration not viable option (e.g. poor soils, hotspot contributing area, etc.)**
- **Aesthetic benefit**

Tree Box Filter

Advantages:

- **Hydrologic Benefits**
  - **Volume***
  - **Rate***

***Some studies[4] have shown minimal volume and rate reductions; would expect the greatest benefit to come from smaller storms as larger storms are bypassed.**

4 – University of New Hampshire Stormwater Center, 2007

Tree Box Filter

Advantages:

- **Water Quality Benefits**
  - **Temperature**
  - **Common street pollutants such as TSS, phosphorous, nitrogen, metals, oil and grease, and others**
  - **Performance similar to bioretention treatment due to similar process**

Tree Box Filter

AECOM

Advantages:

- **Water Quality Benefits**

% Pollutant Removal From Various Tree Box Filters				
	Charles River Watershed Association	**University of New Hampshire Stormwater Center**	**Green Street Systems**	**Filterra**
TSS	85	95	>83	85
Total Phosphorus	74	-	>60	60-70
Nitrogen	68 (Total N)	35 (Dissolved inorganic N)	>50 (Total N)	42-45
Metals	82	95	35-95	58-82
Total Petroleum Hydrocarbons	-	90	-	-
Oil and Grease	-	-	>80	>93 (predicted)
Bacteria	-	-	>85	-

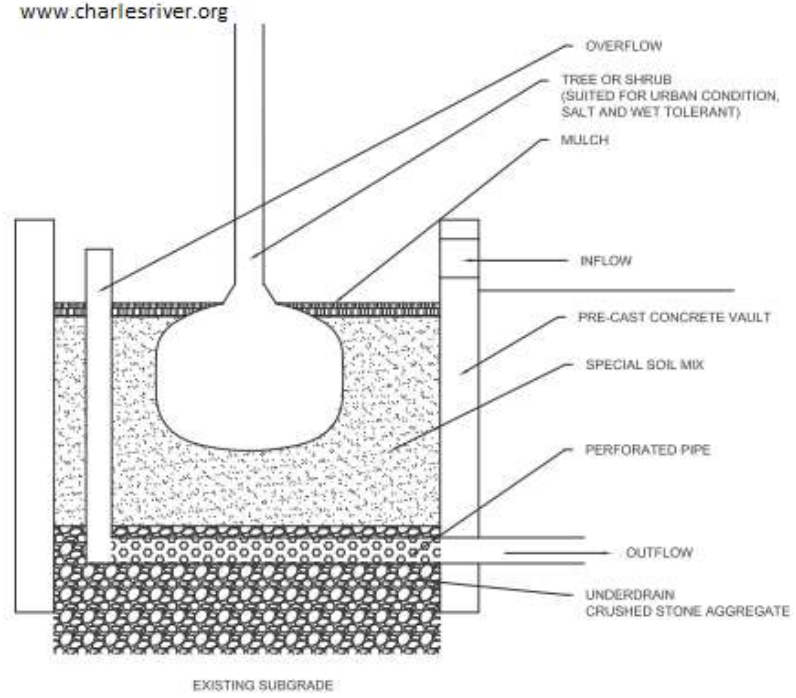
Tree Box Filter

Disadvantages:

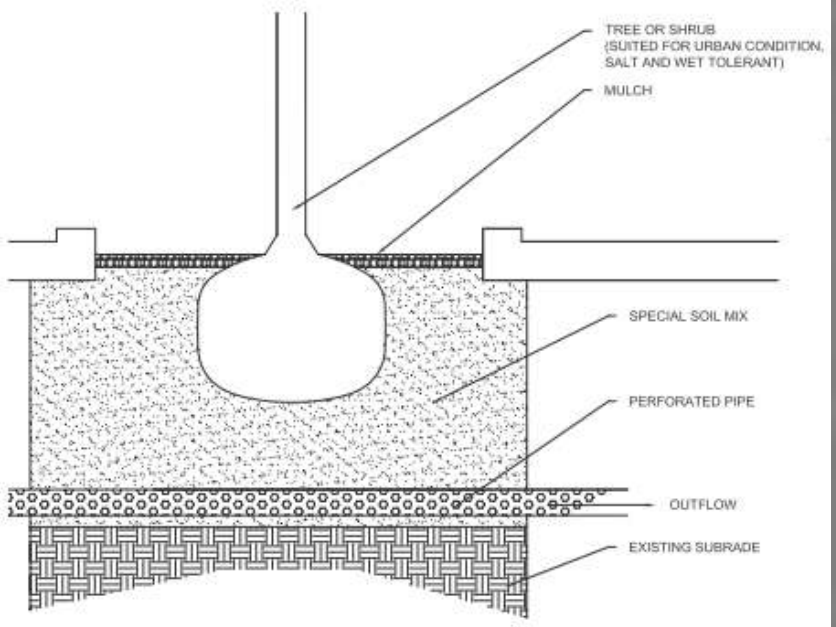
- **Small size**
  - **Only able to treat small area**
  - **Not designed to treat large volumes**
  - **Many filters may be necessary to have significant impact on watershed scale**
- **Water quality treatments may be less effective with too large of a contributing area**
- **Watering may be necessary to sustain tree health during dry weather periods**

Tree Box Filter

Design:



Adapted from:
Low Impact Development Technologies
for Stormwater Management
http://www.unh.edu/erg/cstev/Presentations/index.htm
Accessed 01/22/2008



Adapted from:
Urban Horticultural Institute, New York
http://www.hort.cornell.edu/uhi/outreach/csc/article.html
Accessed 06/16/08

Tree Box Filter

Design:

- **Typically:**
  - **3” mulch layer on top**
  - **3’ filter media:**

    80% sand, 20% compost (minimum 10% organic material)
  - **4” diameter min. perforated underdrain (if used)**
  - **3’ min. from seasonably high groundwater table or impermeable layer**

Tree Box Filter

Design Considerations:

- **Vegetation:**
  - **Native, drought/salt tolerant species**
  - **Don't use species with aggressive root growth to prevent clogging**
  - **Consider landscaping requirements and/or priorities**

Tree Box Filter

Design Considerations:

- **Maintenance access**
- **Overflow:**
  - **Include an overflow for large rainfall events**
  - **Ensure discharge is to a stabilized outlet if discharging to surface conveyance**

Tree Box Filter

AECOM

Design: Infiltration vs. Flow-through

- **Infiltration:**
  - **Recommend at least 1 soil boring per filter to determine underlying soil's infiltration capacity.**
  - **Minimum 2 in/hr infiltration rate for underlying soil**
- **Flow-through:**
  - **Recommend impermeable liner or closed concrete container for areas with low natural infiltration rates, high groundwater, SWMU areas, hotspot areas.**
    - **Cutoff valve can be installed for hotspots to prevent spill material from entering storm drain.**
  - **Include observation well to monitoring clogging**

Tree Box Filter

Design: Sizing

- **Proprietary designs**
- **Sizing a function of:**
  - **Filter surface area**
  - **Drainage area**
  - **Drainage area to be treated**
  - **Desired volume to be treated (typically WQv or other small volume)**
- **Example (east coast):**
  - **To treat 90% of 0.5 acre drainage area, two 6'x6' boxes would be recommended**

Tree Box Filter

Maintenance:

- **Vegetation:**

  Remove trash, remove weeds, replace mulch, replace vegetation, water during periods of drought

- **Structural components:**

  Inspect inlets, outlets, underdrains, planter structure and other components for integrity and function. Clean out when necessary

- **Soils:**

  Verify infiltration rates, test for accumulation of pollutants

Tree Box Filter

AECOM

Maintenance Schedule:

- **1st 6 months of operation:**

  Rainfall events > 0.5 inches or twice in 6 months

- **There after:**

  Rainfall events > 1 year event (1.7 inches for Fort Carson) or annually

- **Replacement:**

  May be necessary after 25 years of operation

- **Some vendors may include 1st/2nd year maintenance with purchase**

Tree Box Filter

Cost Considerations:

- **Materials:**

  Approx. $8,000 - $24,000/unit/acre treated[3,5]

- **Installation:**

  Approx. $1,500 - $6,000/unit[3,5, 6]

- **Maintenance:**

  Approx $100 – $500/year[3] (self maintenance)

  Approx $ 325 - $800/year[7] (Contractor)

3 – Charles River Watershed Association, 2008

5 – LIDStormwater.net, 2011

6 – University of New Hampshire Stormwater Center, 2007

7 – Filterra.com, 2011

Additional Information

- http://www.treeboxfilter.com/design.htm
- http://www.filterra.com/
- http://ciceet.unh.edu/unh_stormwater_report_2007/treatments/tree_box/design.php (University of New Hampshire Stormwater Center)
- www.charlesriver.org
- http://www.lowimpactdevelopment.org/fairfax.htm
- http://www.phillyriverinfo.org/WICLibrary/SWFS4_April2008.pdf
- http://www.dec.ny.gov/docs/water_pdf/swdmredevelop.pdf
- http://www.cwp.org/documents.html

Questions?

http://www.filterra.com/index.php/product/

http://www.epa.gov/owow/NPS/lid/section438/pdf/final_sec438_eisa.pdf

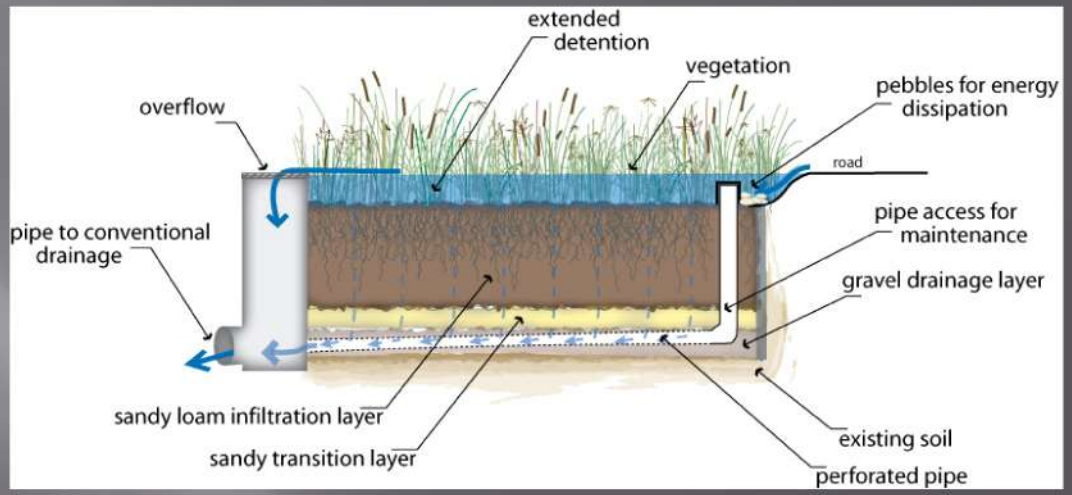
[redacted] - AECOM

- Vegetation –
- Design Guide and Criteria, Plant species

Water Sensitive Urban Design-In Built Form

AECOM

Bioretention / Raingardens



Stream Restoration

AECOM

LID Category	CSD Reduction Benefit Annual Volume Reduction Per Unit Size [MG/yr] *(Infiltration Areas)*	Flooding Reduction Benefit 5-yr Storm Peak Flow Reduction Per Unit Size [cfs] *(Infiltration Areas)*	Unit Cost	Additional Benefits	Game Piece Unit Size *(Footprint Area)*	Drainage Area Treated *(Footprint Area)*
Eco-Roof	1.4	1.7	$1,500,000	• Improves Air Quality • Reduces Energy Consumption • Enhances Community Spaces • Increases Biodiversity	10 Commercial Roofs *(100,000 ft²)*	½ City Block *(100,000 ft²)*
Cistern	1.4	1.9	$160,000	• Reduces Water Demand	70,000 Gallon Tank *(1,560 ft²)*	1 City Block *(210,000 ft²)*
Bioretention	1.6 *(2.0)*	2.6 *(3.2)*	$250,000	• Improves Air Quality • Enhances Community Spaces • Increases Biodiversity • May Recharge Groundwater	1,000 LF of One Lane *(10,000 ft²)*	¾ City Block *(120,000 ft²)*
Rain Garden*	NA *(1.6)*	NA *(2.5)*	$80,000	• Recharges Groundwater • Enhances Community Spaces • Increases Biodiversity	120 Residential Yards *(12,000 ft²)*	½ City Block *(120,000 ft²)*
Detention Basin	1.5 *(1.8)*	1.7 *(2.0)*	$84,000	• May Recharge Groundwater	50,000 Gallon Pond *(2,800 sf²)*	¾ City Block *(140,000 ft²)*
Constructed Wetland	1.6	1.7	$105,000	• Improves Air Quality • Enhances Community Spaces • Increases Biodiversity	50,000 Gallon Pond *(2,800 sf²)*	¾ City Block (140,000 ft²)
Urban Forest	1.7	2.7	$978,000	• Improves Air Quality • Enhances Community Spaces • Increases Biodiversity	1,300 Mature Trees *(300,000 ft²)*	3.5 miles*** *(300,000 ft²)*
Stream Daylighting**	1.9	2.7	$800,000	• Enhances Community Spaces • Increases Biodiversity	800 Linear Feet *(8,000 ft²)*	Varies *(Varies)*
Permeable Pavement	1.6 *(2.0)*	2.6 *(3.2)*	$150,000	• May Recharge Groundwater	1,000 LF of One Lane *(10,000 ft²)*	¾ City Block *(150,000 ft²)*

Vegetation

- **Trees**
  - **Alnus tenuifolia - Native Thin-Leaf Alder**
  - **Amelanchier alnifolia - Saskatoon Serviceberry**
  - **Celtis occidentalis - Common Hackberry**
  - **Cratageus douglasii - Douglas Hawthorn**
  - **Gymnocladus dioica - Kentucky Coffeetree**
  - **Populus sargentii - Plains Cottonwood**
  - **Prunus americana - American Plum**
  - **Quercus bicolor - Swamp White Oak**
  - **Quercus macrocarpa - Bur Oak**
  - **Quercus undulata - Wavy-leaf Oak**
  - **Salix amygdaloides - Peach-leaf Willow**
  - **Pinus edulis - Pinyon Pine**

Vegetation

- **Shrubs**
  - **Amorpha fruticosa - Leadplant**
  - **Cornus sericea 'Baileyi' - Red-Twig Dogwood**
  - **Forestiera neomexicana - New Mexico Privet**
  - **Quercus gambelii - Gambel Oak**
  - **Rhus trilobata - Threeleaf Sumac**
  - **Ribes aureum - Golden Currant**
  - **Robinia neomexicana - New Mexico Locust**
  - **Rosa woodsii - Woods Rose**
  - **Salix exigua - Coyote Willow**
  - **Sheperdia argentea - Silver Buffaloberry**
  - **Symphoricarpos albus - White Snowberry**
  - **Symphoricarpos occidentalis - Western Snowberry**

Helpful Links

AECOM

- **External Information Links**
  - **Sustainable Design Reference**
    - http://www.sustainablesites.org/
  - **Stormwater Design Reference**
    - http://www.portlandonline.com/shared/cfm/image.cfm?id=55791
  - **Urban Drainage Publications and Links**
    - http://www.udfcd.org/
  - **Urban Reference**
    - http://www.cityofchicago.org/city/en/depts/water/supp_info/conservation/green_design/bioinfiltration_raingardens.html
  - **Green Roof for Healthy Cities**
    - http://www.greenroofs.org/

Design Storms
Fort Carson CO

➢2 year 24 Hour	2.1 Inches/24 Hours
➢5 year 24 Hour	2.7 Inches/24 Hours
➢10 year 24 Hour	3.2 Inches/24 Hours
➢25 year 24 Hour	3.7 Inches/24 Hours
➢50 year 24 Hour	4.1 Inches/24 Hours
➢100 year 24 Hour	4.6 Inches/24 Hour
➢95% Storm	1.44 Inches/24 Hour