Design of Stormwater Filtering Systems

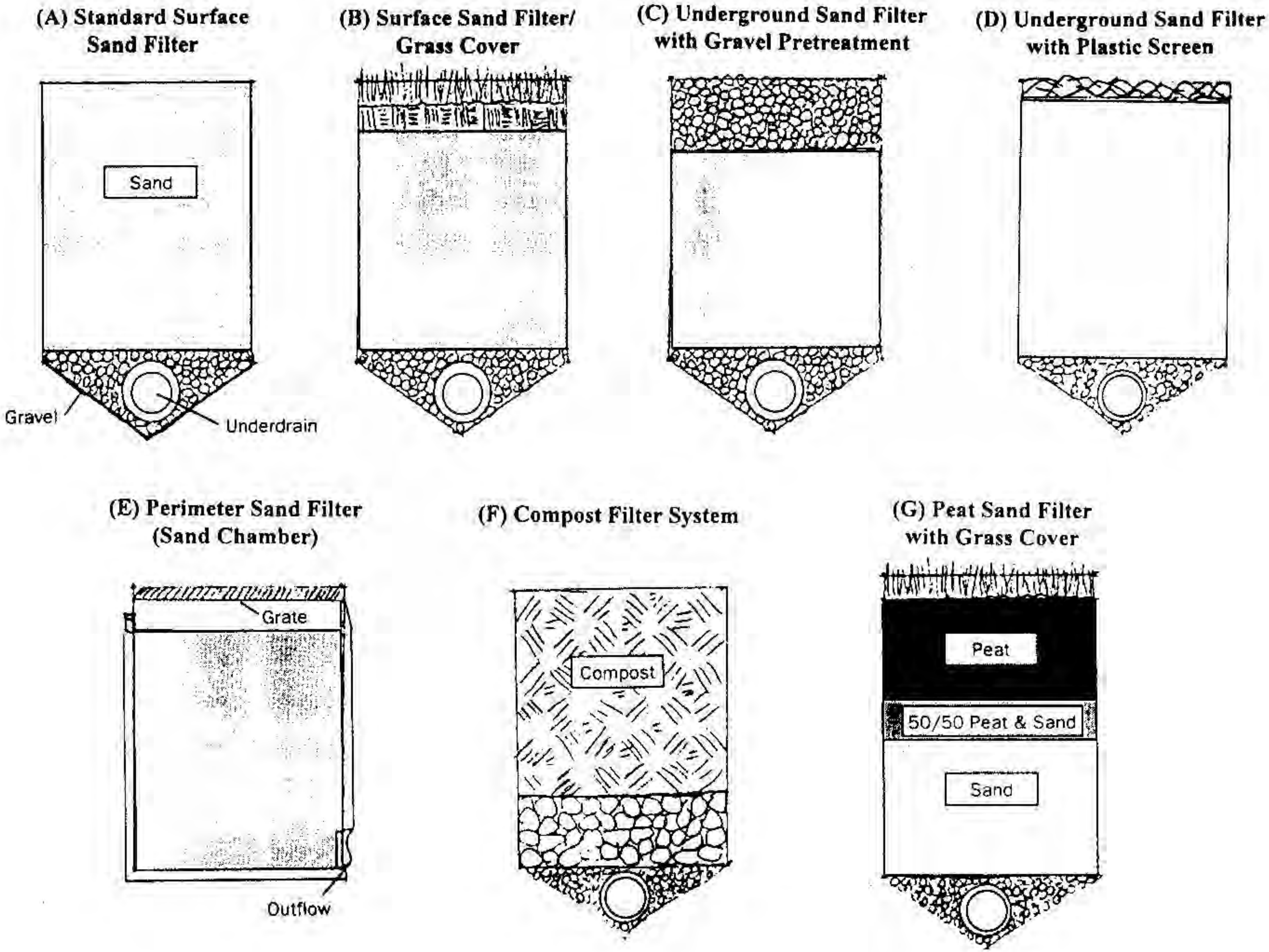
Center for Watershed Protection

Filtering Systems:
Six Design Variations

1. Surface sand filter
2. Perimeter sand filter
3. Organic sand filter
4. Underground sand filter
5. Pocket sand filter
6. Bioretention

Filter System Design Components

- Flow Regulation
  - Diversion of only water quality volume to facility
- Pretreatment
  - Trapping of coarse sediments to extend design life
- Filter Bed and Filter Media
  - Primary treatment component of facility
- Outflow/Overflow
  - Safe conveyance of all storms through facility



(A) Standard Surface Sand Filter
Sand
Gravel
Underdrain
(B) Surface Sand Filter/ Grass Cover
(C) Underground Sand Filter with Gravel Pretreatment
(D) Underground Sand Filter with Plastic Screen
(E) Perimeter Sand Filter (Sand Chamber)
Grate
Outflow
(F) Compost Filter System
Compost
(G) Peat Sand Filter with Grass Cover
Peat
50/50 Peat & Sand
Sand

Filter Media:
Comparison of Different Media Properties

	Sand	Silt Loam	Compost	Peat
Permeability (cm/hr)	3.3	0.1-0.4	-	0.25-140
Water holding capacity (cm/cm)	0.14	.07-0.1	-	.01-0.2
Bulk density (g/cm)	2.65	1.25	1-2	<0.1-0.3
pH	-	5.7	7.8	3.6-6.0
Organic matter (%)	<1	<20	30-70	80-98
Cation exchange capacity	1-3	12-18	66	183-265
Total phosphorus (%)	0	0.09	<0.1	<0.1
Total nitrogen (%)	0	0.15	<1.0	<2.5
Filtration efficiency after 18 in. (%)	93	94	16	47

Sand Filter Selection Guide:
Most Appropriate Option by Land Use

Filter	Ultra-urban	Parking lots	Roads	Residential	Pervious	Rooftop
Surface	Yes	Ideal	Maybe	Maybe	No	Yes
Underground	Ideal	Yes	Maybe	Maybe	No	Yes
Perimeter	Yes	Ideal	Maybe	Maybe	No	Yes
Pocket	Yes	Yes	Maybe	Yes	No	Yes
Organic	Maybe	Yes	No	Maybe	Maybe	Yes
Bioretention	Maybe	Ideal	Yes	Yes	Yes	Yes

Ideal: the best alternative
Yes: greatly suitable
Maybe: may be suitable under certain conditions

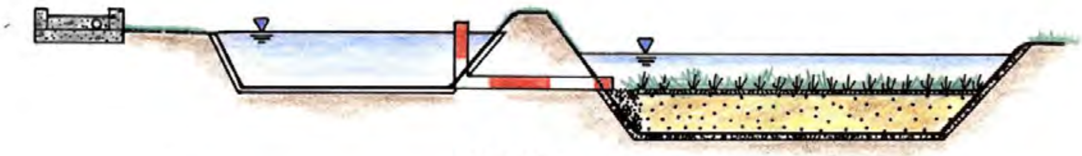
No: seldom or never suitable

Sand Filter Selection Guide:
Key Feasibility Factors

Filter	Space consumed	Minimum head	Maintenance burden	Cost
Surface	2-3%	5 feet	annual	moderate
Underground	none	4 feet	semi-annual	high
Perimeter	2-3%	3 feet	annual	moderate
Pocket	2-3%	3 feet	annual	moderate
Organic	1-2%	5 feet	annual	high
Bioretention	5%	4 feet	semi-annual	low

Surface Sand Filter:
Design Features

- Aboveground facility
- First developed in Austin, Texas
- Wet or dry pretreatment (3 ft. min.)
- 18-inch sand filter bed
- Exfiltration or underdrain system
- Concrete or earth construction
- Designed to treat larger drainage areas



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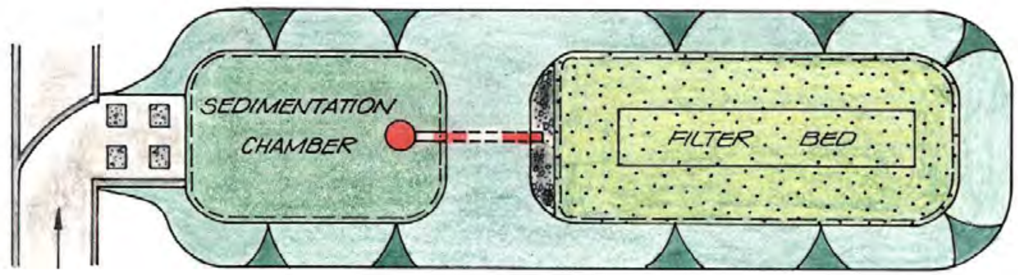

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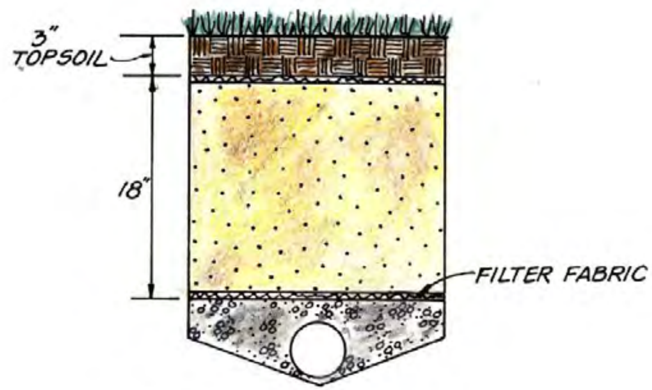

TYPICAL SECTION

SURFACE SAND FILTER


The runoff from this parking lot in Austin, TX drains to the surface sand filter in the midpoint of this slide.


This slide, also from Austin, TX, shows the sedimentation chamber (foreground) and filter bed (background) of a surface sand filter. Note the combination of earthen fill to the right and a concrete shell for the filter itself.
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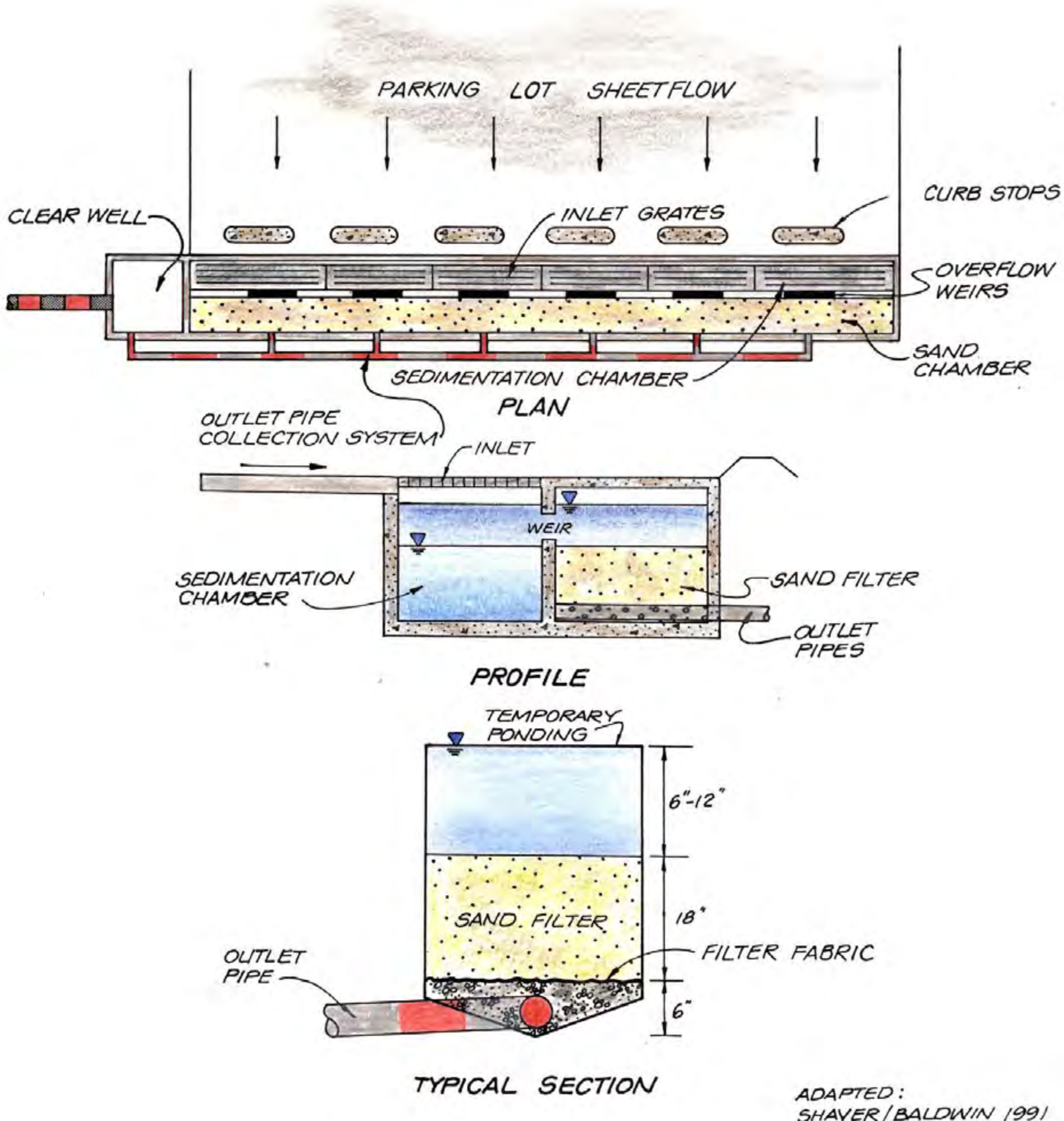
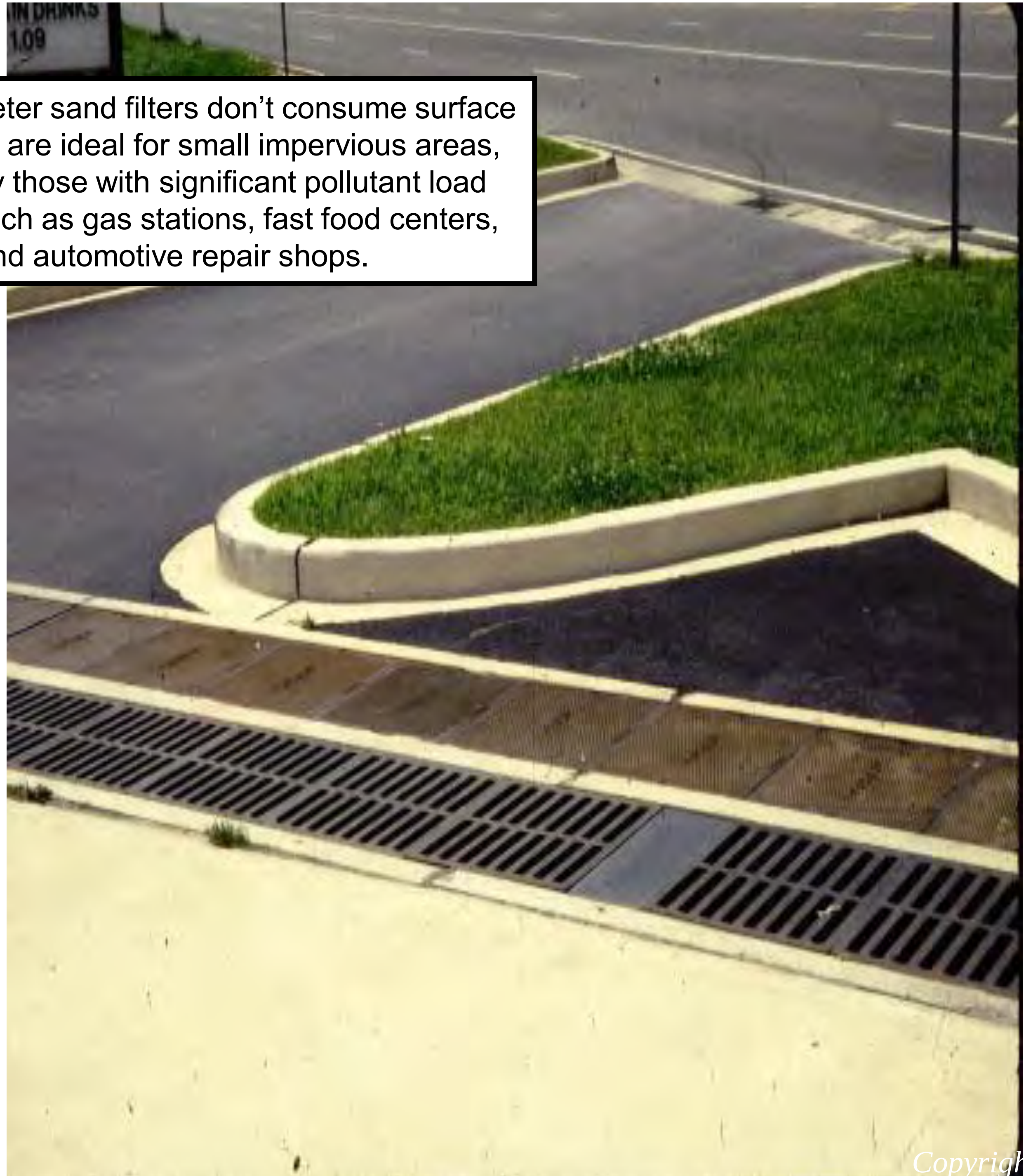
Perimeter Sand Filter:
Design Features

- Located at the perimeter of parking lots
- Developed originally in Delaware
- Two parallel trench chambers
- Two foot wet pool pretreatment
- 18 inch sand filter bed
- Underdrain system
- Ideal for small, highly impervious areas
- Ideal for flat areas with relatively low available head



PERIMETER SAND FILTER

Since perimeter sand filters don't consume surface space, they are ideal for small impervious areas, particularly those with significant pollutant load potential such as gas stations, fast food centers, and automotive repair shops.



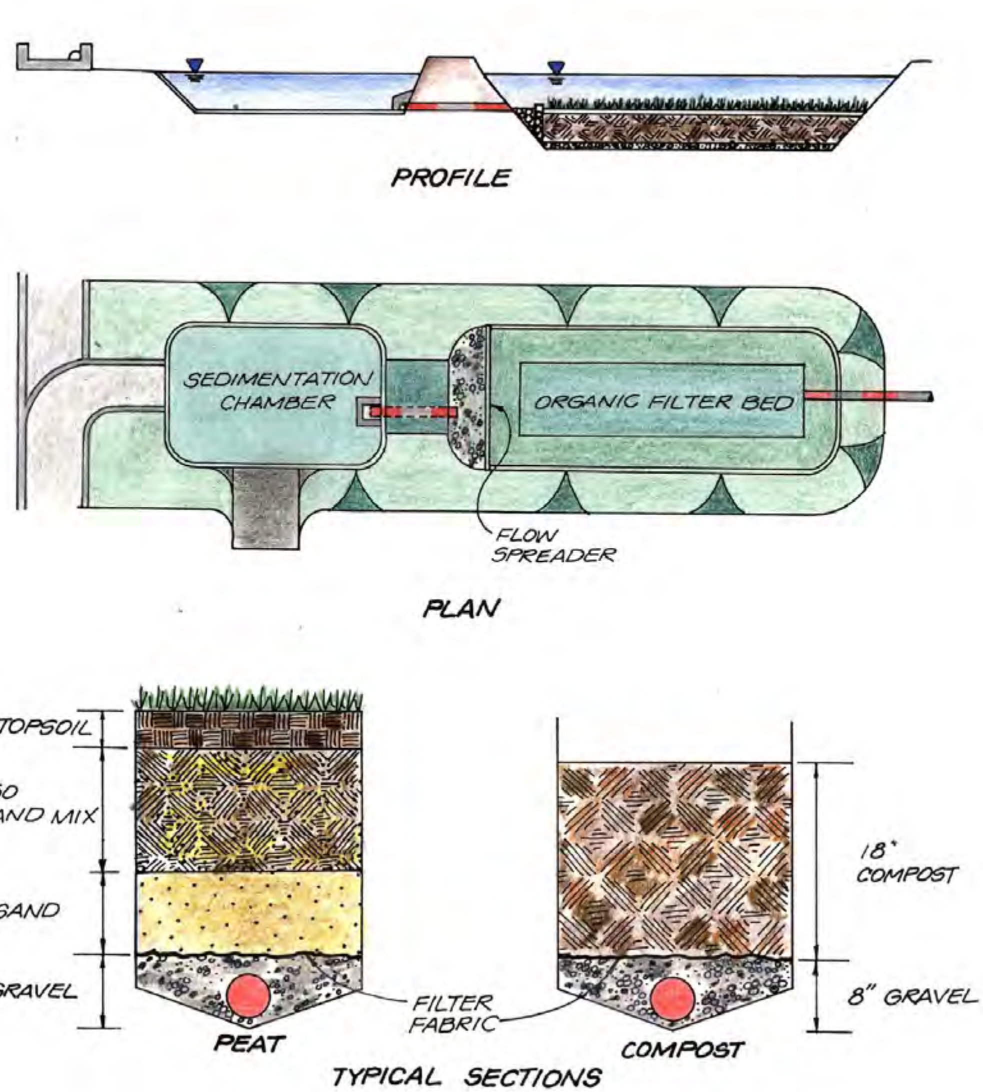
This slide shows precast concrete forms of the two chambered perimeter sand filter. Note the weir slots in the center wall, and the holes for the pipes (to the left) to carry outflows from the bottom of the sand bed to the storm drain system.

Organic Filter:
Design Features

- Aboveground filter system
- Organic medium replaces or augments sand
- Peat & leaf compost, two most common media
- 24-inch peat/sand filter bed
- 18-inch compost filter bed (proprietary system: CSF Treatment Systems, Inc.)
- Exfiltration or underdrain system
- Cover crop desirable for peat/sand system

Peat Sand Filters

- Peat Qualities:
  - High cation exchange capacity
  - High C:N:P ratio (microbial)
  - High organic matter content (80-98%)
  - Moderately decomposed, fibric or hemic (reed-sedge)
  - Stays in place



ORGANIC FILTER


This is a peat sand filter in Maryland's piedmont region that uses a vegetative cover on the surface of the filter bed.
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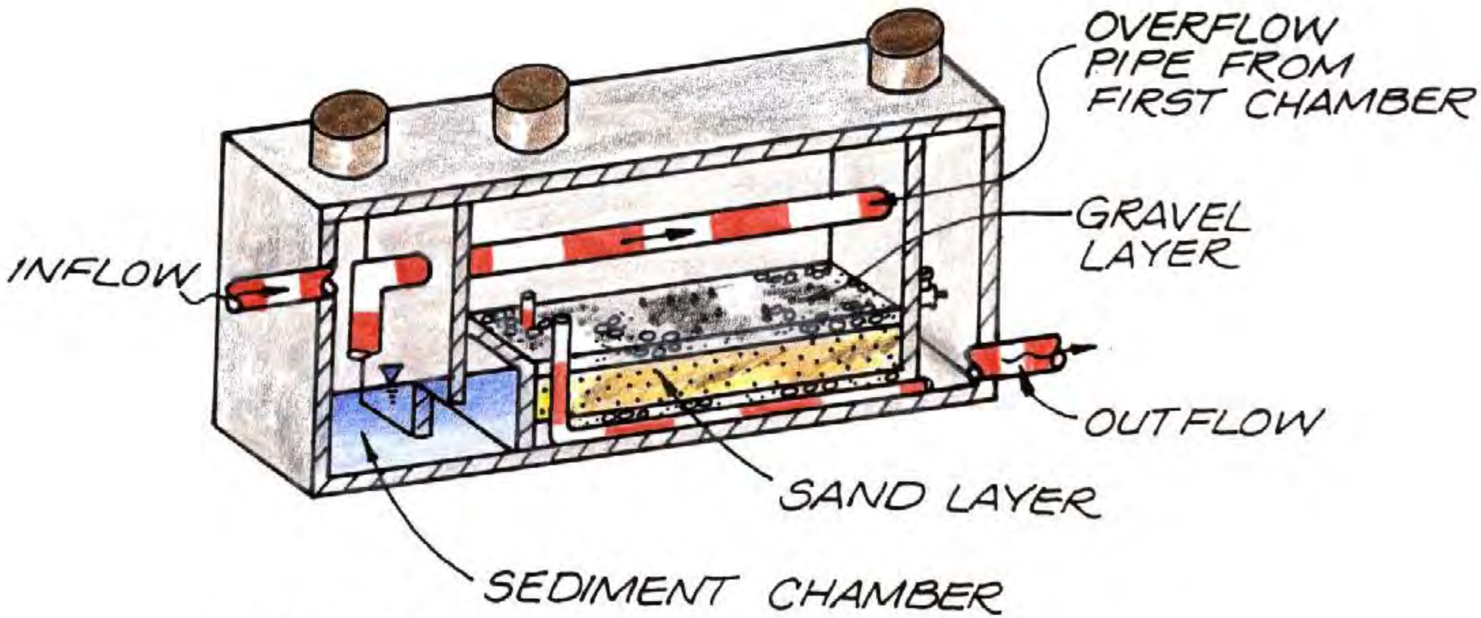
This slide shows a compost filter from the Pacific Northwest. The facility contains a small pretreatment chamber and two compost filter beds in the background.

Underground Sand Filter:
Design Features

- Below-ground facility
- Developed in District of Columbia
- Three foot wet pool pretreatment
- 24 inch sand filter bed
- Underdrain system
- Confined space considerations



UNDERGROUND SAND FILTER W/ BYPASS PIPE


This slide shows the construction of an underground sand filter in progress.
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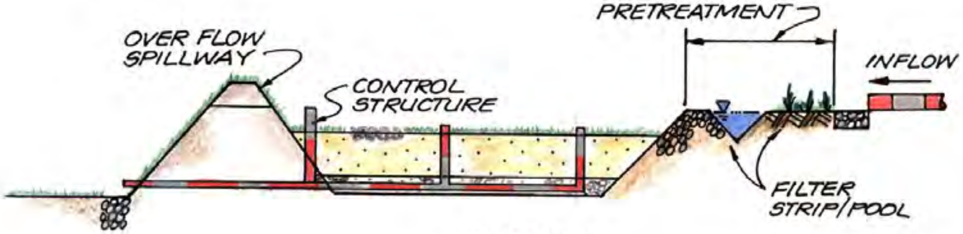
Pocket Sand Filter:
System Components

- Simplified low cost alternative
- Primarily for very small sites
- Level spreader, grass filter, plunge pool pretreatment
- 18 inch sand filter bed
- Exfiltration or underdrain system
- Cover crop with pea gravel window



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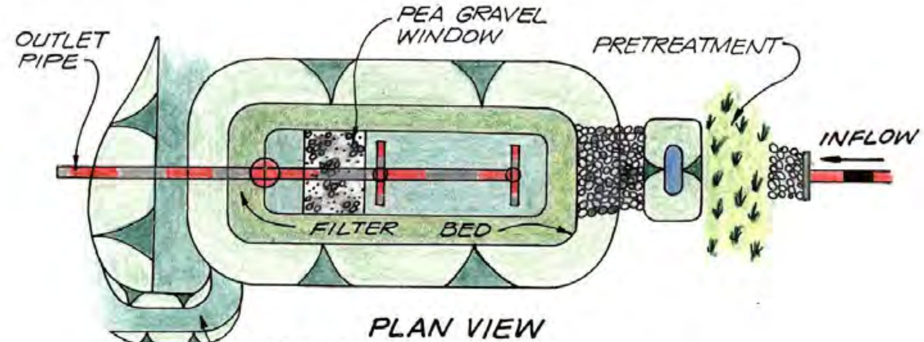
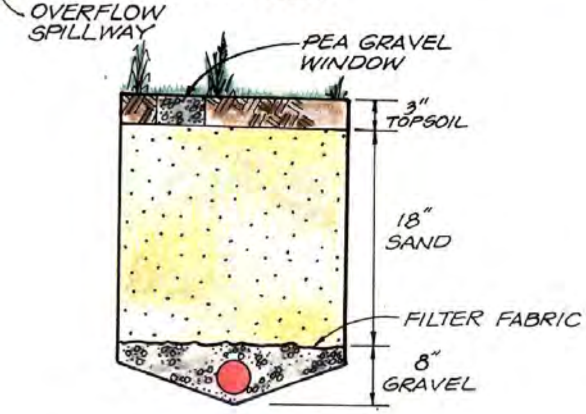


PLAN VIEW



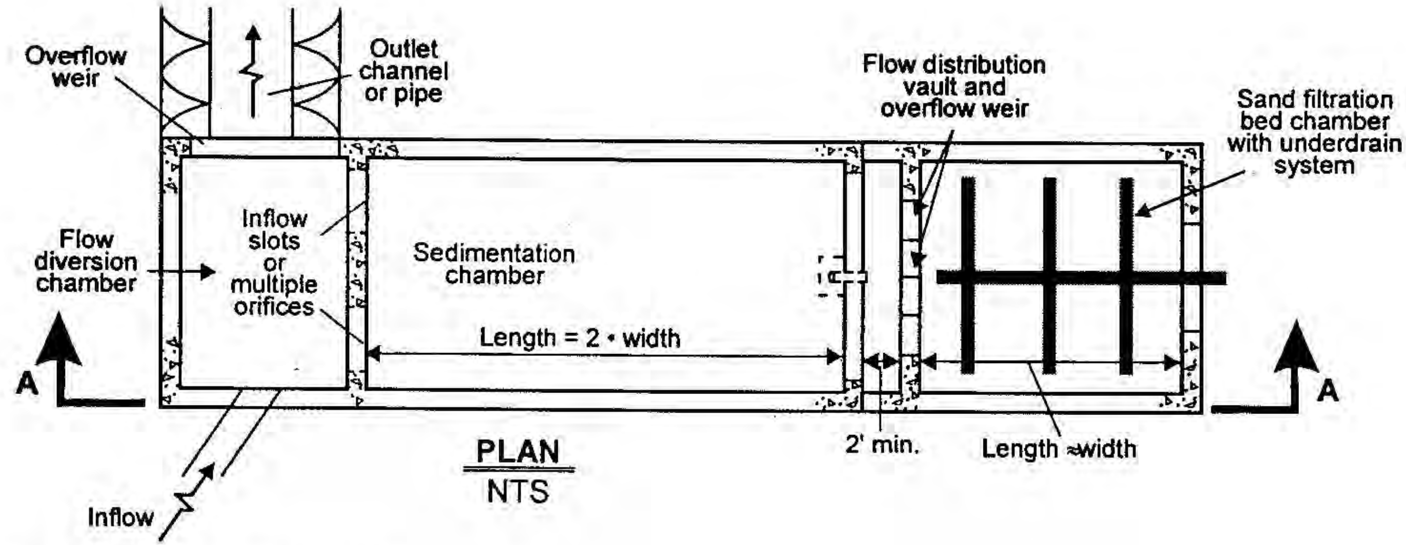
TYPICAL SECTION

POCKET SAND FILTER

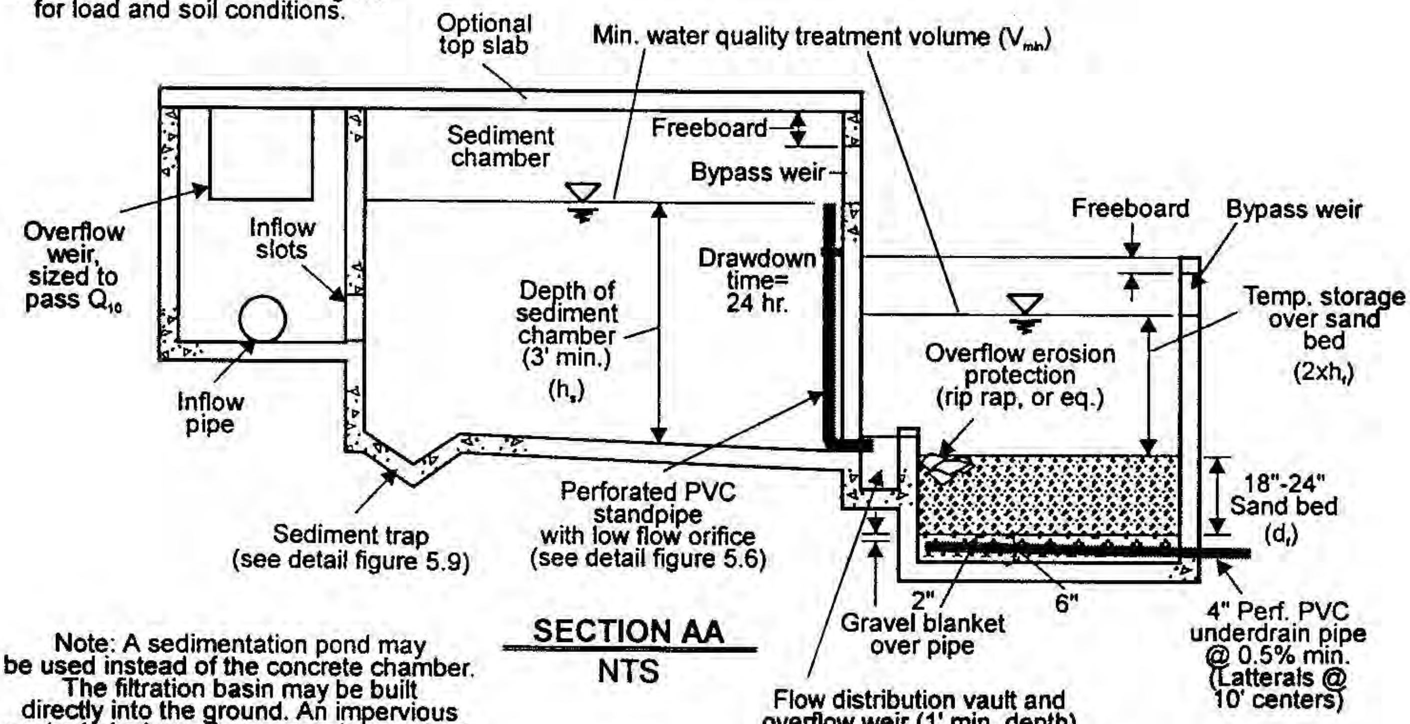

This slide shows a pocket sand filter in central Maryland. The drainage area consists of a small active recreational area, including tennis courts, basketball courts, and a community swimming pool.

Sand Filter Flow Regulation

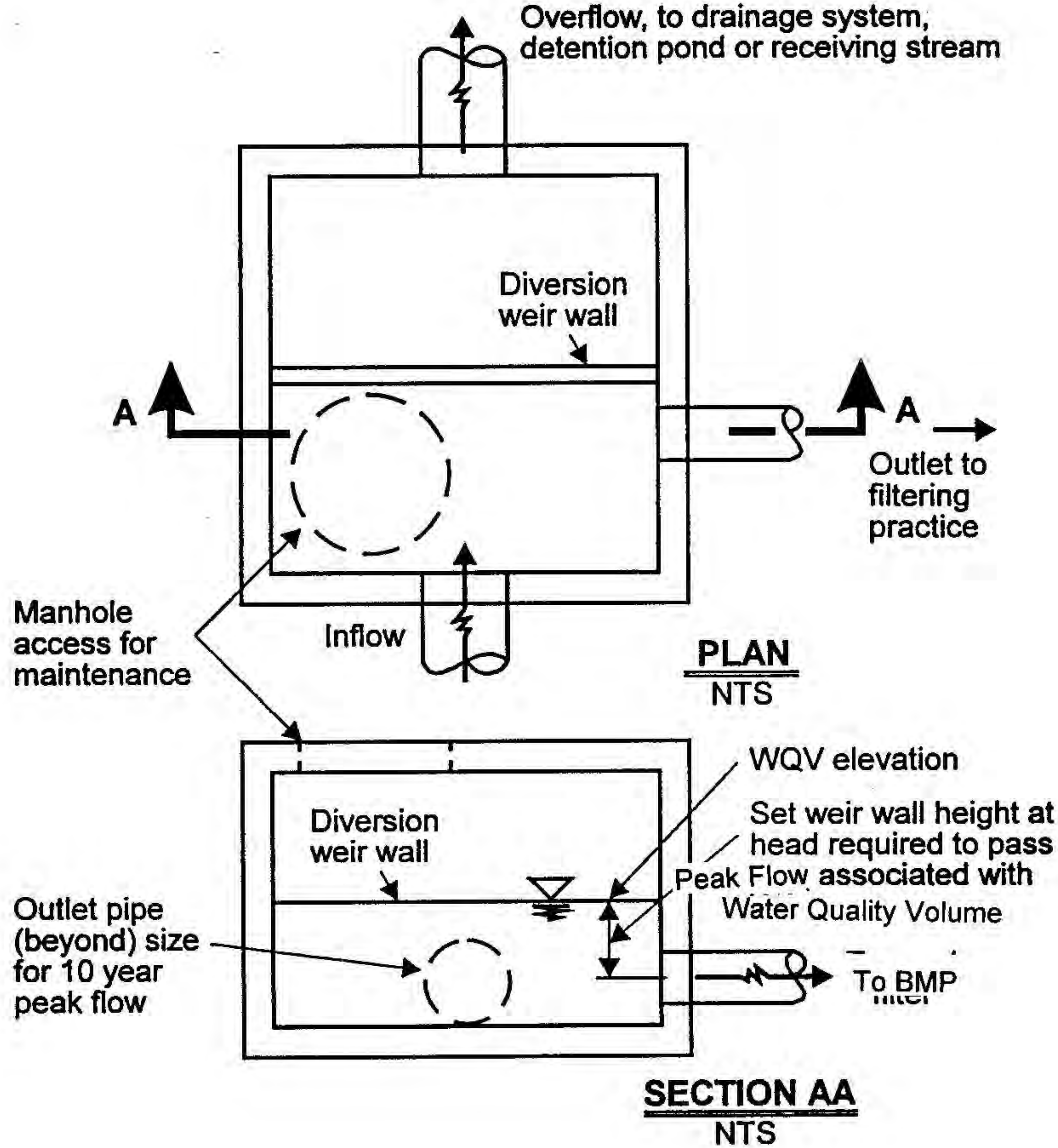
- Locate off-line to handle only WQv storm
- Requires flow diversion structure to bypass larger storms
- Diversion structure can either be located at facility (preferred) or upstream



Note: Structural concrete designed for load and soil conditions.



Note: A sedimentation pond may be used instead of the concrete chamber. The filtration basin may be built directly into the ground. An impervious geotechnical membrane may be required.



Overflow, to drainage system, detention pond or receiving stream
Diversion weir wall
A
A
Outlet to filtering practice
Manhole access for maintenance
Inflow
PLAN
NTS
WQV elevation
Set weir wall height at head required to pass Peak Flow associated with Water Quality Volume
Diversion weir wall
Outlet pipe (beyond) size for 10 year peak flow
To BMP
SECTION AA
NTS

Sand Filter Pretreatment:

Alternative Techniques for Different Filter Options

- Surface sand and organic filters
  - Dry detention for 24 hours, or
  - Wet pool with dry detention above
- Underground sand filter
  - Wet pool at least 3 feet deep & dry detention above
- Perimeter sand filter
  - Wet pool with 2 foot depth & dry detention above
- Pocket sand filter
  - Concrete level spreader, filter strip & plunge pool

Sand Filter Pretreatment:
Sizing Criteria

- Area based on WQ_V
- Camp-Hazen equation: $A_s = -(Q_o/W)*Ln(1-E)$
- $A_s = 0.066\ (WQ_V)\ ft^2$ for $I < 75\%$
- $A_s = 0.0081\ (WQ_V)\ ft^2$ for $I > 75\%$
- $V_{min} = 3/4\ (WQ_V)$

Sand Filter Bed:
Sizing Criteria

- Darcy's Law
  - $A_f = WQ_V*(d_f)/[k*(h_f + d_f)(t_f)]$ where:
    - A_f = surface area of filter (ft^2)
    - WQ_V = treatment volume (ft^3)
    - d_f = filter bed depth (ft) - can vary depending on the site conditions but should not be more 24" (18" is the standard)
    - k = coefficient of permeability (ft/day)
    - h_f = average head above filter bed (ft) - varies depending on the site conditions, but should not exceed 6 feet
    - t_f = time to filter through bed (days) - A value of 40 hours is recommended

Sand Filter Media:
Coefficient of Permeability Values

Filter Media	Coefficient of Permeability (k, ft/day)
Sand	3.5
Peat/sand	2.75
Compost	8.7

Sand Filter Media:
Design Components

- 18-24 inch filter bed (sand or organic)
- Cover crop for some applications
  - Grass-peat/sand, surface, pocket
  - Pea gravel window-pocket
  - Gravel and geotextile-underground
- Observation wells/cleanout pipes

Sand Filter Overflow: System Components

- Flow distribution vault or weir
- 6-11 inch gravel underdrain system
- 4-6 inch perforated collection pipe
- Overflow or bypass weir or pipe
- Gate valve for dewatering
- Outlet chamber

Construction Specifications

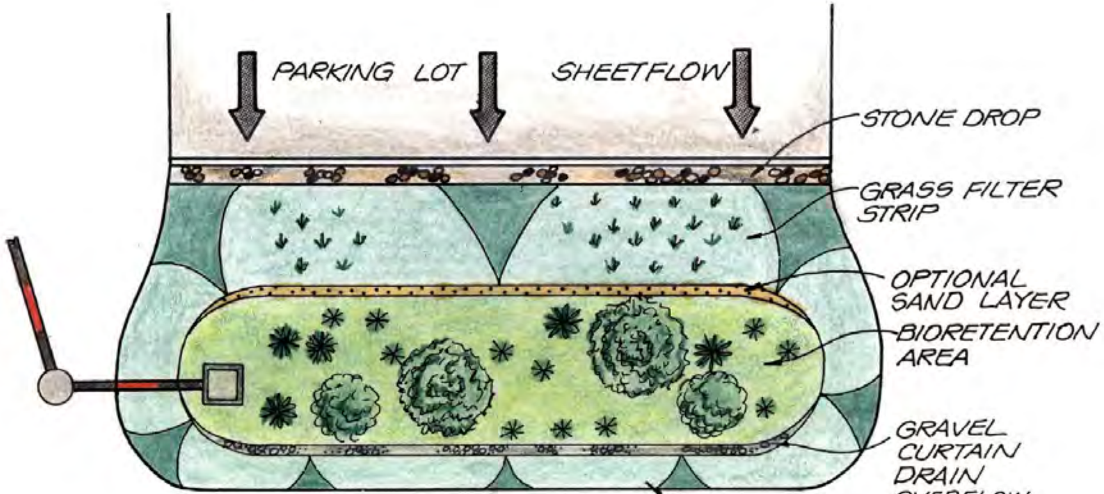
Parameter	Specification	Size
Sand	ASTM C-33 concrete, medium agg.	.02-.04in.
Peat	Ash content: <15%	Reed-sedge
	pH range: 5.2-4.9	hemic peat
	Bulk density: .12-.15 g/cc	
Leaf Compost	CFS Treatment Systems	
Underdrain		
gravel	AASHTO M-43	1/2-2 in.
Geotextile		
fabric	ASTM D-751, D-1117, and D-1682	
Imperm. Liner	ASTM D-751, D-412, D-624, and D-471	30 mil thick
PVC Piping	AASHTO M-278	4-6 in. (Sch. 40)

Sand Filter Maintenance

Maintenance Element	Inspection Frequency	Required Actions
Debris cleanout	Quarterly	Remove buildup
Vegetation	Monthly (during growing season)	Regular mowing, repair erosion, revegetate
Filter bed chamber	Semi-annually	Replace clogged surface, or manual manipulation
Sedimentation chamber	Semi-annually	Clean-out when depth > 12 in., limit vegetation height
Structural components	Annually	Repair/replace damaged components
Outlet/overflow structures	Annually	Repair/replace clogged/failing elements

Bioretention Areas

- Economical for small sites (1 acre or less)
- Easy to construct
- Compatible with commercial landscaping needs
- Utilizes existing open space
- Limited performance data suggests pollutant removal comparable to or better than other filtering practices



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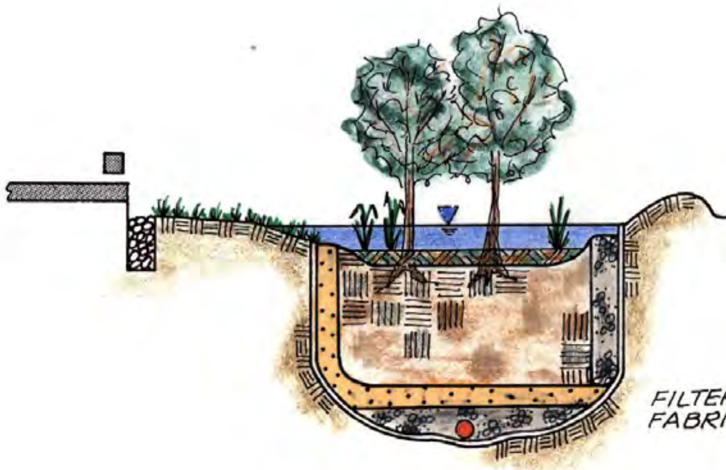

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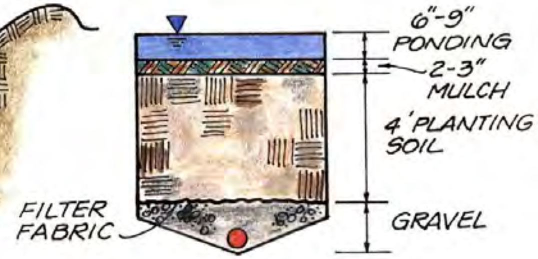
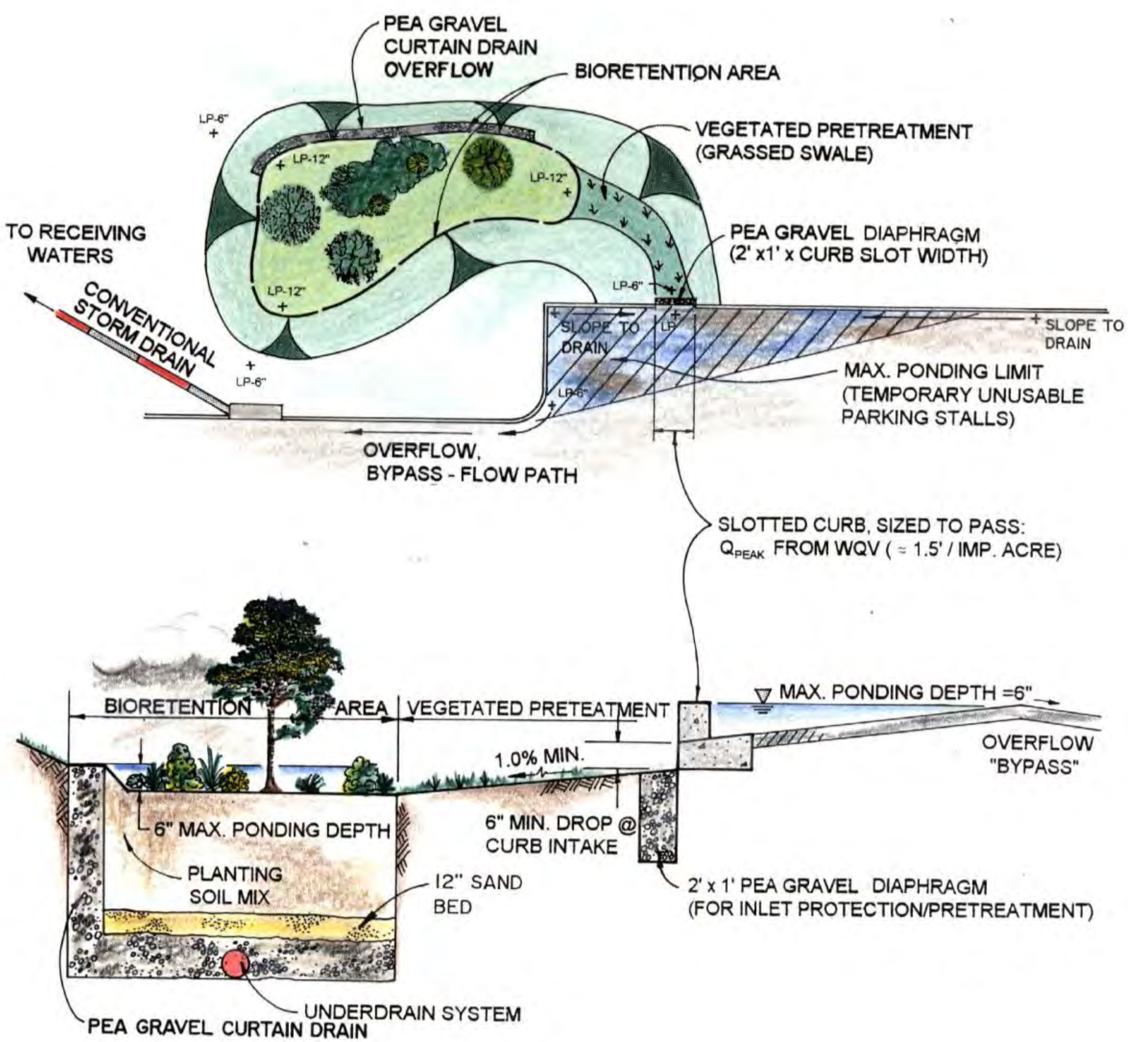


TYPICAL SECTION

BIORETENTION FILTER



SOURCE: ADAPTED FROM PRINCE GEORGE'S COUNTY - DESIGN MANUAL FOR THE USE OF BIORETENTION IN STORMWATER MANAGEMENT, 1993


Here is a bioretention island in a parking lot. Note the curb cuts that allow the runoff to access the vegetated depression.


Here is a similar design set up just after a rain event.


This design variation receives both parking lot and street runoff.


Smaller bioretention cells are easily and attractively incorporated into individual lots, as this slide shows.

Bioretention:
System Components

- Off-line design
- Pea gravel filter diaphragm
- Grass buffer strip
- Ponding area
- Pea gravel overflow drain
- Organic layer (mulch)
- Planting soil
- Plant materials (trees/shrubs)
- Gravel/pipe underdrain system

Bioretention Flow Regulation:
Diversion for Off-line Design

- Runoff capture of WQv
- Two flow splitter design options
  - Within drainage system
  - Within filtering practice itself
- Simple three step design
  - Compute WQv and WQ peak discharge
  - Size low flow hydraulic structure to practice
  - Size larger storm overflow structure

Bioretention Pretreatment:

Filter Strip Sizing Criteria

Parameter	*Impervious Parking Lots*				*Residential Lawns*				*Notes*
Maximum inflow approach length (feet)	35		75		75		150		
Filter strip slope	✂2%	👓2%	✂2%	👓2%	✂2%	👓2%	✂2%	👓2%	Maximum slope=6%
Filter strip minimum	10'	15'	20'	25'	10'	12'	15'	18'	

Bioretention Pretreatment:

Grass Channel Sizing Guidance

Parameter	***≤33% Impervious***		***Between 34% & 66% Impervious***		***≥67% Impervious***		***Notes***
Slope	≤2%	≥2%	≤2%	≥2%	≤2%	≥2%	Maximum slope = 4%
Grassed channel min.	25	40	30	45	35	50	Assumes a 2' wide

Bioretention Filter Media: Design Components

$$A_f = WQV ((d_f)/k((h + d_f)(t_f))$$

where:

A_f = Surface area of the bioretention planting bed (ft^2)

WQv = Water quality treatment volume (ft^3)

d_f = Planting soil bed depth (ft) – 4 ft recommended

k = Coefficient of permeability for planting soil bed (ft/day) - k = 0.5 ft/day: Median value of a silt loam

h = Average height of water above the bioretention bed (ft); h_{avg} = ½*h_{max} - h is equal to 3", assuming a maximum ponding depth of 6" above the planting soil bed

t_f = Time required for the Water Quality Treatment Volume (WQV) to filter through the planting soil bed - A value of 72 hours is recommended

Bioretention Filter Media:
Design Components

$$A_f = D.A. \times 5.0\% \times R_v$$

Where:

A_f = the required surface area of the bioretention facility

D.A. = the drainage area

R_v = the volumetric runoff coefficient

Bioretention Areas:
Specifications

- Minimum width = 15 to 25 feet
- Minimum length = 30 to 50 feet
- Length to width ratio of 2:1 for widths > 15 feet
- Maximum ponding depth = 6 inches
- Maximum planting soil depth = 4 feet
- Drainage area = 0.25 to 1.0 acres
- Maximum slope = 20%
- Maximum entry velocity = 3 feet/second

Landscaping a Bioretention Area

- Minimum 3 species of trees and shrubs (each)
- Trees planted 12 feet on center (1000 stems/acre)
- Native trees and shrubs selected for tolerance for:
  - Pollution
  - Ponding
  - Dry soil
- Mulch layer typically shredded hardwood mulch
- Locate plant material near perimeter but not at inflow
- Care and replacement warranty (80% - one year)
- Normal landscaping maintenance