Design of Filtering Practices in the Chesapeake Bay Watershed

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Created to deliver targeted training on new tools and practices to improve the quality of stormwater runoff.

http://www.cbstp.org
Filtering Practices in the Chesapeake Bay Watershed

Outline:
- Types of Filters
- Filter Configuration Selection
- Filter Media Selection and Performance
- Filter Design
- Filter Maintenance and Operation
Types of Filters in the Chesapeake Bay Watershed

Quite the range of system configurations and filter media:

- Surface Sand Filter
- Pocket Sand Filter
- Organic Filter
- Perimeter Sand Filter
- Underground Sand Filter
- Bioretention*

*Bioretention is a form of a filter media, however it will not be covered in this session. Please refer to the Bioretention Training module for a detailed presentation of Bioretention design.
Types of Filters in the Chesapeake Bay Watershed

Surface Sand Filter with turf cover

Surface Sand Filter

Perimeter (Delaware) Sand Filter

Underground Sand Filter
## Filter Configuration Selection: Most Appropriate Option by Land Use

<table>
<thead>
<tr>
<th>Filter</th>
<th>Ultra-</th>
<th>Parking</th>
<th>Roads</th>
<th>Residential</th>
<th>Pervious</th>
<th>Rooftop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>Maybe</td>
<td>Ideal</td>
<td>Maybe</td>
<td>Maybe</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Underground</td>
<td>Ideal</td>
<td>Yes</td>
<td>Maybe</td>
<td>Maybe</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Perimeter</td>
<td>Yes</td>
<td>Ideal</td>
<td>Maybe</td>
<td>Maybe</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Pocket</td>
<td>Maybe</td>
<td>Yes</td>
<td>Maybe</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Organic</td>
<td>Maybe</td>
<td>Yes</td>
<td>No</td>
<td>Maybe</td>
<td>Maybe</td>
<td>Yes</td>
</tr>
<tr>
<td>Bioretention</td>
<td>Maybe</td>
<td>Ideal</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Ideal:** the best alternative  
**Yes:** very suitable  
**Maybe:** may be suitable under certain conditions  
**No:** seldom or never suitable
## Filter Selection Guide: Key Feasibility Factors

<table>
<thead>
<tr>
<th>Filter</th>
<th>Space consumed (^1)</th>
<th>Minimum head (^2)</th>
<th>Maintenance burden (^3)</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>2-3%</td>
<td>5 feet</td>
<td>annual</td>
<td>moderate</td>
</tr>
<tr>
<td>Underground</td>
<td>none</td>
<td>4 feet</td>
<td>semi-annual</td>
<td>high</td>
</tr>
<tr>
<td>Perimeter</td>
<td>2-3%</td>
<td>3 feet</td>
<td>semi-annual</td>
<td>moderate</td>
</tr>
<tr>
<td>Pocket</td>
<td>2-3%</td>
<td>3 feet</td>
<td>annual</td>
<td>moderate</td>
</tr>
<tr>
<td>Organic</td>
<td>1-2%</td>
<td>5 feet</td>
<td>annual</td>
<td>high</td>
</tr>
<tr>
<td>Bioretention</td>
<td>5%</td>
<td>4 feet</td>
<td>annual</td>
<td>moderate</td>
</tr>
</tbody>
</table>

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1. Percentage of contributing impervious drainage area
2. Drop from water surface inflow to invert out
3. Maintenance Burden and Cost should also consider ease of access for inspections and maintenance
Typical Filter Schematics and Design

- Surface Sand Filter
- Pocket Sand Filter
- Organic Filter
- Perimeter Sand Filter
- Underground Sand Filter
Surface & Pocket Sand Filters

Applied to drainage areas ≤ 2 acres in size (essentially the same as Bioretention) with the following exceptions:

- The bottom is lined with an impermeable filter fabric and always has an underdrain.
- The surface cover is sand, turf or pea gravel.
- The filter media is 100% sand.
- The filter surface is not planted with trees, shrubs or herbaceous materials.
- The filter has two cells: a dry or wet sedimentation chamber preceding the sand filter bed.

The Surface Sand Filter is the least expensive filter option for treating hotspot runoff. The use of bioretention areas is generally preferred at most other sites.
Organic Media Filter

- Essentially the same as surface filters;
- Sand is replaced with an organic filtering media, such as:
  - Peat/sand filter; and
  - Compost filter system.
- Organic media can achieve higher pollutant removal for metals and hydrocarbons due to the increased cation exchange capacity of the organic media.
- However, they also tend to provide lower nutrient removal.
Perimeter Sand Filter

- Includes the basic design elements of a sedimentation chamber and a filter bed;
- Design flow enters the system through grates, usually at the edge of a parking lot.
- Usually designed as an on-line practice (i.e., all flows enter the system), but larger events bypass treatment by entering an overflow chamber.

One major advantage of the Perimeter Sand Filter design is that it requires little hydraulic head and is therefore a good option for sites with low topographic relief.
Underground Sand Filter

- Filtering components are modified to fit into an underground chamber;
- Designed with an internal flow splitter or overflow device that bypasses large storm flows to prevent resuspension and flushing;
- Generally more expensive to construct and maintain, but they consume very little space and are well suited to ultra-urban areas
Media Filters: Alternative Media

- Other media being used and/or tested include sand, sand with iron oxides, perlite, zeolite, alumina, chitosan, leaf compost, granular polymers (polypropylene), and others.

- Design specifications in the Bay Watershed are geared for only those media listed in the various design manuals.

- Each state will determine (individually or through reciprocal agreements) if alternate media are allowed, and how systems should be sized.
### Media Filters In Different Water Resource Settings

<table>
<thead>
<tr>
<th>Practice</th>
<th>Spec No.</th>
<th>Karst Terrain</th>
<th>Coastal Plain</th>
<th>Trout Waters</th>
<th>Ultra-Urban</th>
<th>Hotspots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filtering Practices</td>
<td>12</td>
<td>Preferred</td>
<td>Accepted</td>
<td>Accepted</td>
<td>Preferred</td>
<td>Preferred</td>
</tr>
</tbody>
</table>

**KEY**

- **Preferred Practice:** widely feasible and recommended
- **Accepted Practice:** can work depending on site conditions
- **Restricted Practice:** extremely limited feasibility
- **Prohibited Practice:** do not use due to environmental risk

**NOTES:**

1. CSN Tech Bulletin No. 1
2. CSN Tech Bulletin No. 2
3. CSN Tech Bulletin No. 6
4. CSN Tech Bulletin No. 5
5. CWP (2004)

**Note:** Hotspots may require specific media or configurations.
Typical Urban Pollutant Loading

- Sediment
- Oil & grease
- Nutrients
- Metals
- Gross Organic debris
- Trash
Typical Hydraulic Loading On A Media Filter:

Will require increased surface area or frequent maintenance
Typical Urban Hotspot Loading On A Media Filter:

Will require frequent inspections and possibly routine maintenance
Extreme Urban Hotspot Loading:

No presentation is complete without the extreme example:

Solution: Alternative configuration and/or media, and a robust pre-treatment designed specifically for oil & grease
Media Filtration Performance in the Chesapeake Bay Watershed:

Box and whisker data plots:

- Highest value
- 75th percentile value
- Median value
- Average value
- 25th percentile value
- Lowest value
Media Filtration Performance in the Chesapeake Bay Watershed:

Data primarily represents sand filters

Source: National Pollutant Removal Performance Database, v.3, CWP 20007
Media Filtration Performance in the Chesapeake Bay Watershed:

- Most filters are nitrate leakers and have low N removal
- High removal rates for metals and hydrocarbons
- Organic media can further enhance metal and hydrocarbon removal, but diminishes nutrient and organic carbon removal
- Modest removal of bacteria
- One of the few practices that does not interact with groundwater and therefore “preferred” for stormwater hotspots (with appropriate pre-treatment and maintenance).
## Media Filtration in the Chesapeake Bay Watershed: Sand Filters

<table>
<thead>
<tr>
<th>Stormwater Function</th>
<th>Level 1 Design(^2)</th>
<th>Level 2 Design(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Runoff Reduction (RR)</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Total Phosphorus (TP) Removal (^1)</td>
<td>60%</td>
<td>65%</td>
</tr>
<tr>
<td>Total Nitrogen (TN) Removal (^1)</td>
<td>30%</td>
<td>45%</td>
</tr>
<tr>
<td>Channel Protection</td>
<td>Limited – The Treatment Volume diverted off-line into a storage facility for treatment can be used to calculate a Curve Number (CN) Adjustment.</td>
<td></td>
</tr>
<tr>
<td>Flood Mitigation</td>
<td>None. Most filtering practices are off-line and do not materially change peak discharges.</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Change in the event mean concentration (EMC) through the practice.

\(^2\) Level 1 and Level 2 design refer to standard and enhanced design criteria (CWP 2007); refer to next slide.
# Filter Design and Performance Criteria

<table>
<thead>
<tr>
<th>Level 1 Design (RR:0; TP:60; TN:30)$^1$</th>
<th>Level 2 Design (RR:0 $^2$; TP:65; TN:45)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_v = [(1.0)(Rv)(A)] / 12$ minus the volume reduced by upstream RR</td>
<td>$T_v = [(1.25)(Rv)(A)] / 12$ minus the volume reduced by upstream RR</td>
</tr>
<tr>
<td>One cell design</td>
<td>Two cell design</td>
</tr>
<tr>
<td>Sand media</td>
<td>Sand media with an organic layer</td>
</tr>
<tr>
<td>Contributing Drainage Area (CDA) contains pervious area</td>
<td>CDA is nearly 100% impervious</td>
</tr>
</tbody>
</table>

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1 RR = Runoff Reduction credit; TP = Total Phosphorus reduction credit; TN = Total Nitrogen Reduction credit

2 May be increased if the 2$^{nd}$ cell is utilized for infiltration in accordance with Stormwater Design Specification No. 8 (Infiltration) or Stormwater Design Specification No. 9 (Bioretention).

The Runoff Reduction (RR) credit should be proportional to the fraction of the $T_v$ designed to be infiltrated.
Sand Filter Sizing and Design

Two major Design Components:

- Sedimentation Chamber (pre-treatment);
- Filter chamber
Sand Filter Pretreatment: Sizing Criteria (Maryland)

In MD, the sizing of the surface area of the pre-treatment chamber \((A_s)\) is based on the percent impervious cover:

- \(I > 75\%\) impervious will in theory have higher fraction of coarse sediment (target particle size of 40 um); requiring less sedimentation surface area.
- \(I \leq 75\%\) targets 20 micron \((mm)\) particle.
Sand Filter Pretreatment: Sizing Criteria (Maryland) (continued)

- $A_s$ based on Camp-Hazen equation:

$$ A_s = \frac{Q_o}{W} \times E' $$

where: $A_s$ = Sediment basin surface area;
$Q_o$ = discharge from basin = ($WQv/24$ hr)
$W$ = Particle size settling velocity
PSD = 20 um = 0.0004 ft/sec
PSD = 40 um = 0.0033 ft/sec
$E'$ = sediment trapping efficiency = 2.30
Sand Filter Pretreatment: Sizing Criteria (Maryland) (continued)

Substituting and solving for the sedimentation surface area ($A_s$):

- $A_s = 0.066 \times (WQ_v) \, \text{ft}^2$ for $I \leq 75$
- $A_s = 0.0081 \times (WQ_v) \, \text{ft}^2$ for $I > 75$

- The minimum depth is 3 ft; and
- $V_{\text{min}} = 3/4 \times (WQ_v)$
Sand Filter Pretreatment: Sizing Criteria in Virginia

In Virginia, the Pre-Treatment Sedimentation Chamber is:

- 3 ft minimum depth;
- Sized to accommodate at least 25% of the total Treatment Volume (inclusive).
- Alternate methods of pre-treatment are allowed.
The surface area ($A_f$) of all horizontal bed media filters is sized using Darcy’s Law:
Sand Filter Sizing and Design: Filter Chamber and Sand Bed

The surface area \((A_f)\) of all horizontal bed media filters is sized using Darcy’s Law:

\[
A_f = \frac{(WQv)(d_f)}{[K(h_f + d_f)t_f]}
\]

Where

\(A_f\) = required surface area of filter media \((\text{ft}^2)\)

\(WQv\) = required treatment volume \((\text{ft}^3)\)

\(d_f\) = depth (thickness) of filter media: min 1 ft.;
  typical = 1.5 ft.

\(K\) = Hydraulic Conductivity of media \((\text{ft/day})\)
  partially clogged sand \((\text{ft./day}) = 3.5\)

\(h_f\) = average water depth above filter \((\text{ft})\)
  = \(h/2\); max \(h = 5 \text{ ft.}\)

\(t_f\) = draw down time \((\text{days}) = 1.67 \text{ days}\)
Filter Media: Coefficient of Permeability (Typical Values)

<table>
<thead>
<tr>
<th>Filter Media</th>
<th>Coefficient of Permeability (K, ft/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>3.5</td>
</tr>
<tr>
<td>Peat/Sand</td>
<td>2.75</td>
</tr>
<tr>
<td>Compost</td>
<td>8.7</td>
</tr>
</tbody>
</table>

- The coefficient of permeability represents the permeability of the media when reaching the end of its service life: partially to fully clogged.
- This sizing criterion establishes the surface area of the filter such that it will still function as designed for its entire design service life.
Sand Filter Media: Design Components

- 12-18 inch filter bed (sand or organic) allows for periodic shaving of the surface layer where bio-fouling (algae or organic mat) can blind the filter surface;

- Media cover to facilitate maintenance of underground sand filter
  - Pea gravel layer over geotextile to help reduce bio-fouling by creating an irregular surface with large pore spaces
  - Requires maintenance access suitable for removing large, heavy quantities of material

- Observation well

- Cleanouts for underdrains
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
Alternate Configurations; Alternate Designs

- Manufactured Filters:
  - Verification through the Virginia BMP Clearinghouse;
  - NJ Corporation for Advanced Technology (NJCAT);
  - Technology Acceptance Reciprocity Protocol) (TARP)

- Currently there are no products with verified nutrient performance data applicable to the Chesapeake Bay watershed.

- Refer to:
  http://www.vwrrc.vt.edu/SWC/index.html
Media Filters: Longevity and Maintenance

- Filters are prone to clogging; frequency of maintenance is dependant on relative cleanliness (or dirtiness) of the site;
- Periodic inspections over the course of the first 3 years will help develop a reliable maintenance and inspection cycle;
Media Filters: Longevity and Maintenance

- **Underground** sand filters have unique maintenance and inspection needs:
  - base flow from AC condensers during dry months will promote a heavy agal layer on the sand surface and clogging the filter;
  - Maintenance (and some periodic inspections) will require confined space entry (except for Perimeter – Delaware Sand Filter).
  - Access to the sedimentation chamber and the filter chamber must be sized to accommodate entry and exit of media;

- All filters require periodic removal of the top inch (more or less as needed) of media periodically.
Media Filters: Tips on Improving Performance

- Specifications for sand should limit the amount of fines while also establishing a good mix of coarse sand particle size;
- Limit the amount of pervious area in the contributing drainage area;
- Pretreatment is essential for all filter applications, especially on hotspot land uses;
- Can be combined into other practices (bottom of ED pond or pretreatment to infiltration);
- Need to design effective flow splitters and overflows.