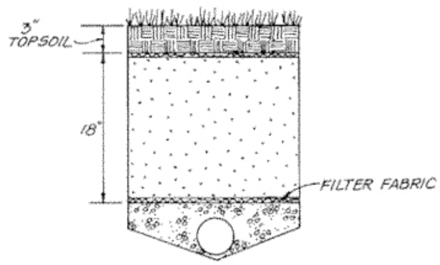
Surface Sand Filters



Description

Also known as filtration basins, filter systems, or media filtration facilities, surface sand filters consist of a pretreatment basin, a water storage reservoir, flow spreader, sand and underdrain piping. A basin liner may also be needed if the treated runoff is not to be allowed to infiltrate into the soil underlying the filtration basin because of groundwater concerns. A related type of filtration system employs organic materials such as peat or compost combined with sand or other materials. The latter types are not discussed in this publication.

Sand filters are intended to address the spatial constraints that can be found in intensely developed urban areas where the drainage areas are highly impervious. They can be used on small urban sites where space is at a premium and where the soils or groundwater concerns would not support an infiltration device.

Sand filters have been demonstrated to be effective in removing many of the common pollutants found in urban stormwater runoff, especially those found in particulate form. They have also been shown to have at least a moderate level of bacterial removal. They have not been effective at removing total dissolved solids and nitrate-nitrogen (subsets of total suspended sediment and nitrogen, respectively).

There are two basic components of a sand filter design: the pretreatment basin and the sand filter. They are both important parts of the design, and neither can be omitted. The pretreatment basin reduces the amount of sediment that reaches the sand filter and helps ensure that stormwater reaches the sand filter as sheet flow. The sand filter traps the finder sediment and sediment-bound pollutants and provides a media for microbial removal of bacteria.

Sand filters work by receiving the first flush of runoff and settling out the heavier sediment in the pretreatment basin. Water flows to and is spread over the sand filter, where pollutants are either trapped or strained out. Sand filters are to be used only for drainage that has been stabilized. Sediment suspended in runoff during construction could quickly clog the sand filter and render it useless.

Purpose

Water Quantity

Flow attenuation	□
Runoff volume reduction	□

Water Quality

Pollution prevention	
Soil erosion	**N/A**
Sediment control	**N/A**
Nutrient loading	**N/A**
Pollution removal	
Total suspended sediment (TSS)	■
Total phosphorus (P)	◧
Nitrogen (N)	◧
Heavy metals	■
Floatables	◧
Oil and grease	◧
Other	
Fecal coliform	◧
Biochemical oxygen demand (BOD)	◧

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

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Drainage areas directed to each sand filter should be less than 5 acres in size. Sand filters are very adaptable, and have few site constraints. They can be applied in areas with thin soils, high evaporation rates, low soil-infiltration rates and limited space.

Sand filters can be used in high-density urban sites with small drainage areas that are completely impervious (such as small parking lots). They can be applicable to many areas that are difficult to retrofit due to space limitations.

Sand filters are most effective when designed as off-line BMPs; they are intended primarily for quality control, not quantity control. A diversion structure, such as a flow splitter or weir, is provided to route the "first flush" of runoff into the sand filter, while the remainder continues on to a stormwater-quantity-control BMP.

Because of the potential for clogging, sand filters should be applied only at sites that have been stabilized and should never be used as sedimentation traps or basins during construction. Any disturbed areas within the sand filter's drainage area should be identified and stabilized to the maximum extent possible.

Advantages

- Applicable in small drainage areas of 1 to 10 acres
- Have few constraints, so can be applied to most development sites
- May require less space than other treatment control BMPs
- Good retrofit capability
- Take up little space and can be used on highly developed and steeply sloped sites
- Provide high removal efficiencies for TSS

Limitations

- Pretreatment required to prevent the filter media from clogging
- Maintenance required every 6 months to 5 years depending on watershed
- Relatively costly to build and install
- An elevation difference of about 4 feet between the inlet and outlet of the filter is usually needed
- Not applicable in areas of high water tables
- Should not be used in areas where heavy sediment loads are expected or in tributary areas that are not fully stabilized
- Generally do not provide quantity control
- Performance reduced if underdrains and filter media freeze

Design Requirements

General Principles and Sizing

The sand filter design is based on Darcy's law:

$$Q = KiA = VA \text{ (since } V = Ki\text{)}$$

where Q = WQ design flow (cfs)

K = hydraulic conductivity (fps)

A = surface area perpendicular to the direction of flow (sf)

i = hydraulic gradient (ft/ft) for a constant head and constant media depth, computed as follows:

$$i = (h + l) / l$$

where h = average depth of water above filter (ft), defined for this design as d/2

d = maximum storage depth above filter (ft)

l = thickness of sand media (typically 1.5 ft)

When water is flowing into the ground, *V* is commonly called the filtration rate. It is ordinarily measured in a percolation test. The filtration rate *V* changes with head and media thickness, although the media thickness is constant in the sand filter design. Table 1 shows values of *V* for different water depths *d* (remember, d = 2h), assuming a media thickness of 1.5 feet and a hydraulic conductivity of 1 inch per hour.

Unlike the the filtration rate *V,* the hydraulic conductivity *K* does not change with head, nor is it dependent on the thickness of the media, only on the characteristics of the media and the fluid. The hydraulic conductivity of 1 inch per hour (2.315×10^{-5} fps) used in this design is based on bench-scale tests of conditioned rather than clean sand. This design hydraulic conductivity represents typical sand-bed condition as silt is captured and held in the filter bed. The designer should determine the correct hydraulic conductivity based on the actual sand used for the filter bed.

For a basic sand filter design, the filter should be sized to completely empty (drawdown time) the design-storm volume in 24 hours or less. Water depth above the filter should be no more than 6 feet. A minimum of one foot of freeboard is recommended when establishing the BMP depth.

Table 1: Sand Filter Design Parameters

	Sand Filter Design Parameters					
Facility ponding depth d (ft)	1	2	3	4	5	6
Filtration rate V (in/hr) *	1.33	1.67	2.00	2.33	2.67	3.0
1/v (min/in)	44	36	30	26	26	20

* *Note:* The filtration rate is not used directly but is provided for information. V equals the hydraulic conductivity K times the hydraulic gradient i. The hydraulic conductivity used is 1 inch/hr. The hydraulic gradient = (h + l) / l, where h = d / 2 and l = the sand depth (1.5 ft).

Source: King County, 1988

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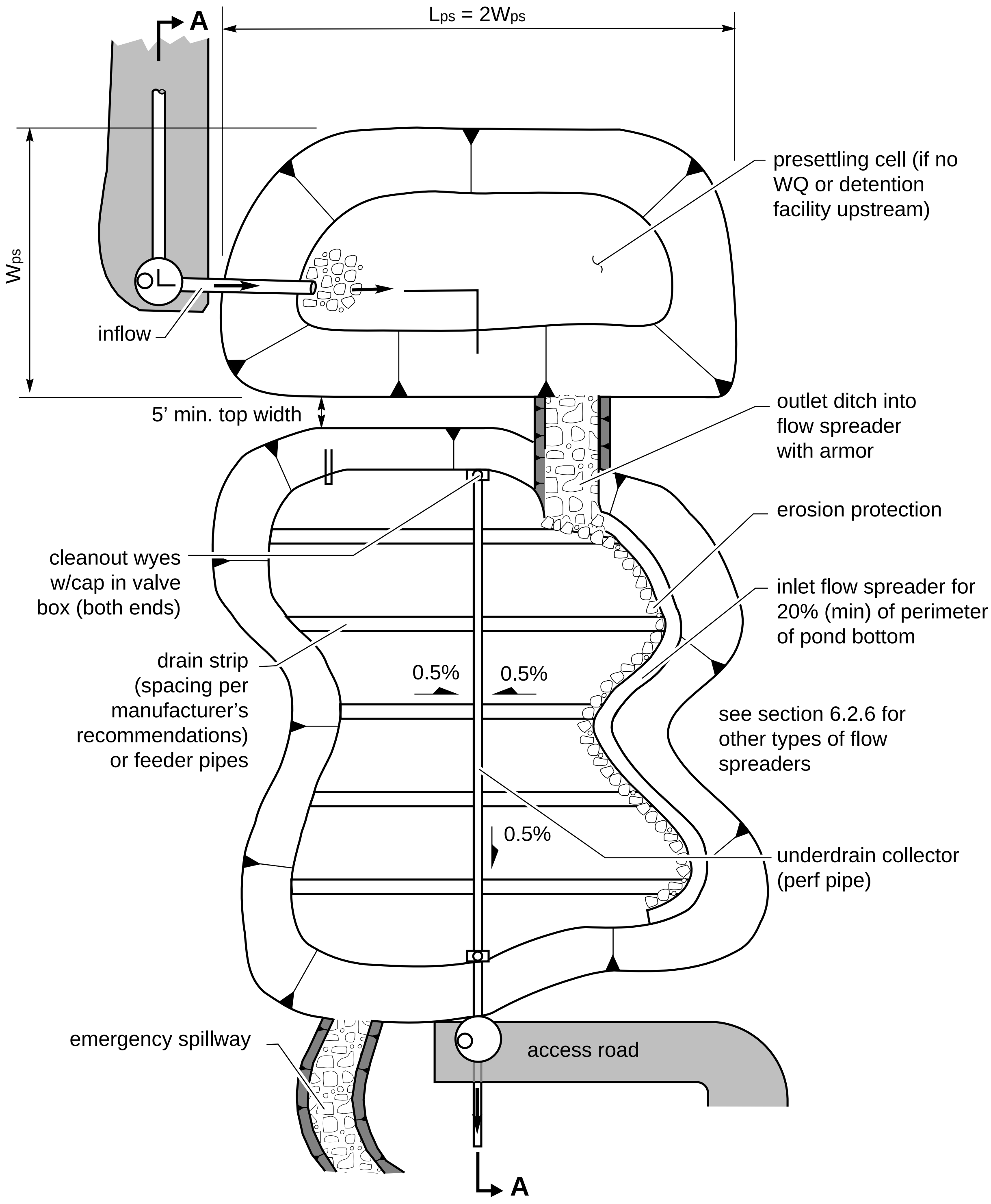

Figure 1: Plan: Surface Sand Filter

Not to Scale

Source: Washington, 2000.

Surface Sand Filters

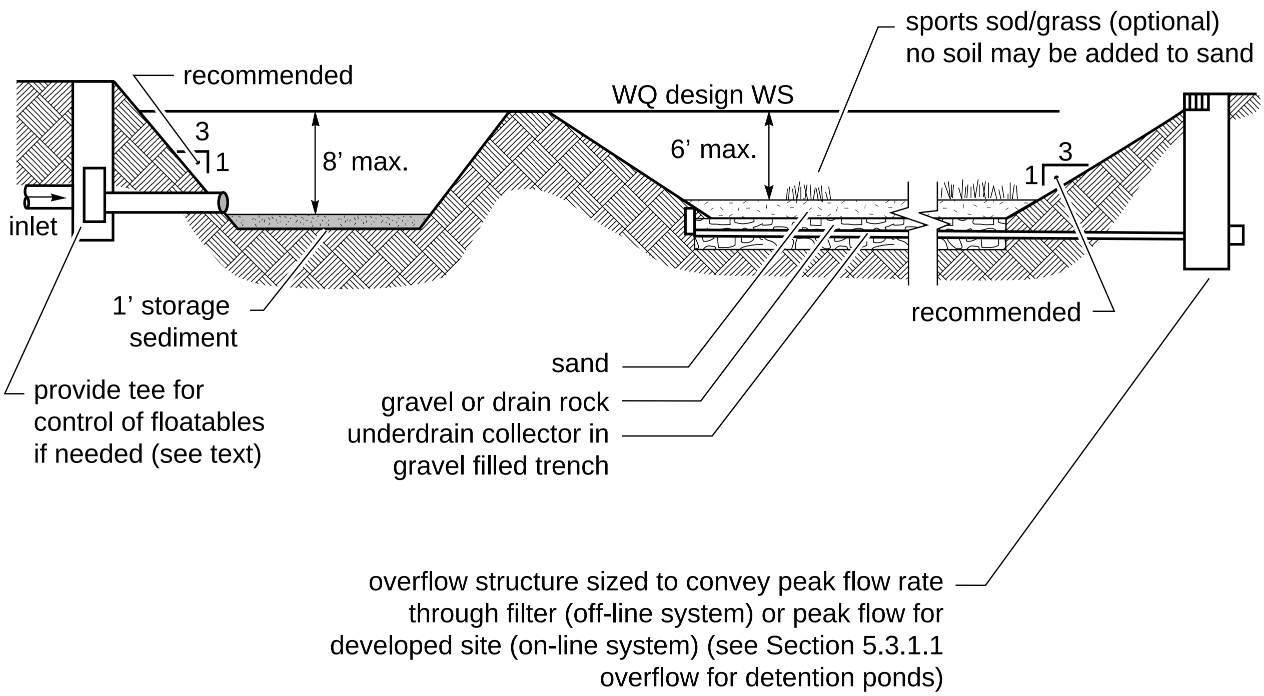

Figure 2: Section A-A: Surface Sand Filter
Not to Scale
Source: Washington, 2000.

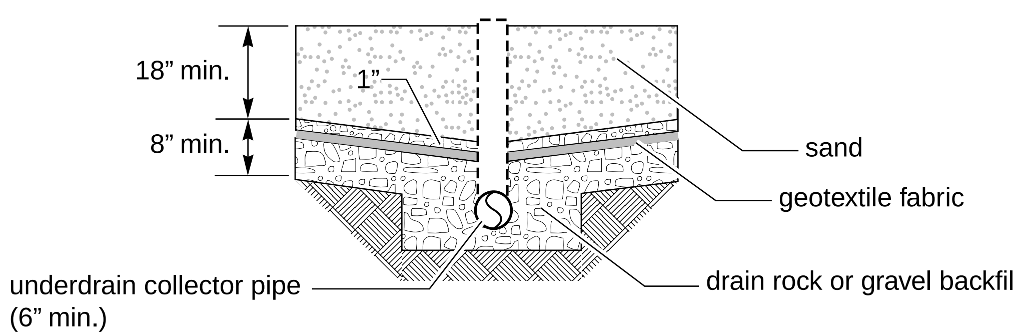

Figure 3: Trench Detail
Not to Scale
Source: Washington, 2000.

Surface Sand Filters

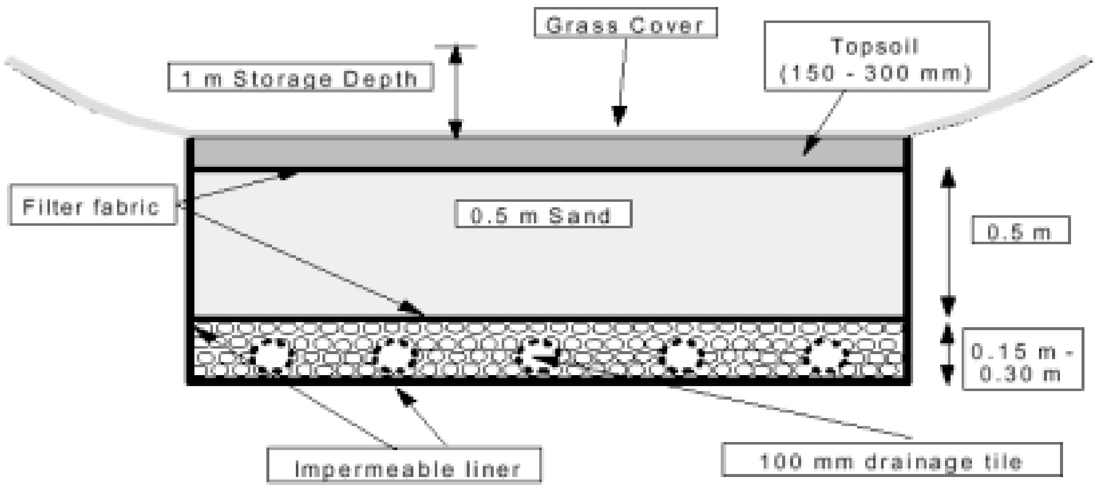

Figure 4: Sand Filter Cross-Section
Not to Scale
Source: Ontario, 1999.

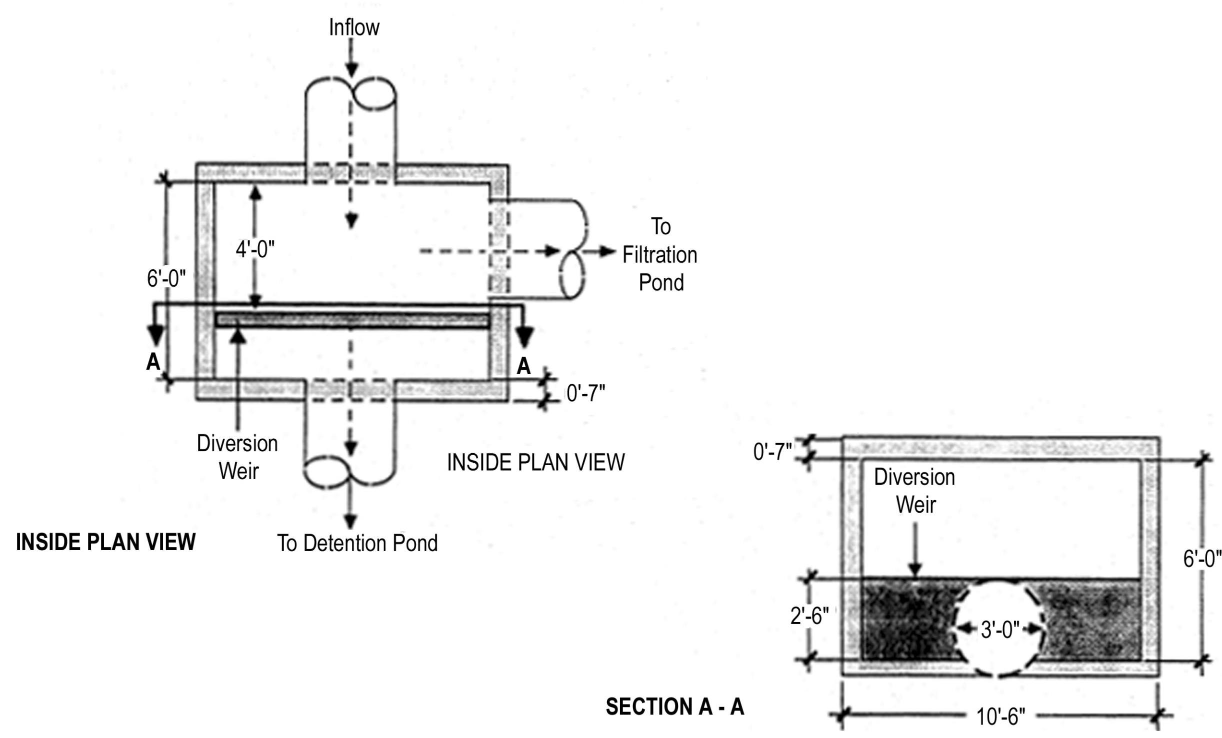

Figure 5: Isolation/Diversion Structure
Not to Scale
Source: Washington, 2000.

Surface Sand Filters

Design (continued)

Requirements

Basic Components

- Surface sand filters generally employ the following layers, from top to bottom: sand, geotextile and an underdrain system.
- Runoff discharging to the sand filter must be pretreated (via a presettling basin, for example) to remove debris and other gross solids and any oil from high-use sites. (The type of pretreatment device will depend on the type of pollutants present.) The length-to-width ratio of the presettling basin should be 3:1 and the depth at 3 to 6 feet.
- Inlet structures (such as flow spreaders, weirs or multiple orifice openings) should be designed to minimize turbulence and to spread the flow uniformly across the surface of the filter media.
- Stone riprap or other dissipation devices should also be installed to prevent gouging of the sand media and promote uniform flow (see Fig. 1). Off-line outlet structures are typically sized for the 15-minute peak flow of a 2-year, 24-hour storm.
- An impermeable liner (clay, geomembrane or concrete) may be required under the filter to protect groundwater or where underflow could damage structures. If the impermeable liner is not required, a geotextile liner should be installed, unless the bed has been excavated to bedrock.

Sand Specification

The sand in a filter must consist of a medium sand meeting the size gradation (by weight) given in Table 2. The contractor must obtain a grain-size analysis from the supplier to certify that the No. 100 and No. 200 sieve requirements are met. A laboratory analysis to determine the sand's hydraulic conductivity K is also highly recommended. The designer should then adjust this number to account for conditioning of the sand during operation.

Underdrain Systems

Several types of underdrains may be used: a central collector pipe (with lateral feeder pipes or a geotextile drain strip in an 8-inch gravel backfill or drain rock bed) or a longitudinal pipe in an 8-inch gravel backfill or drain rock with a collector pipe at the outlet end.

- Hydraulically, the system is typically sized for the 15-minute peak flow from a 2-year, 24-hour storm, with 1 foot of head above the invert of the upstream end of the collector pipe. Local sizing requirements should be used when available.
- Internal diameters of underdrain pipes should be a minimum of 6 inches and 2 rows of half-inch holes spaced 6 inches apart longitudinally (max.), with rows 120 degrees apart (laid with holes downward). Maximum perpendicular distance between two feeder pipes must be 10 feet. All piping is to be schedule 40 PVC or greater wall thickness. Corrugated polyethylene pipe may also be used.

Table 2: Sand Medium Specification

U.S. Sieve Number	Percent Passing
4	95–100
8	70–100
16	40–90
30	25–75
50	2–25
100	<4
200	<2

Source: King County, 1998

- Main collector underdrain pipe should be at a minimum slope of 0.5 percent.

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Table 3: Clay Liner Specifications

Property	Test Method	Unit	Specification
Permeability	ASTM D-2434	cm/sec	1×10^{-6} max.
Plasticity index of clay	ASTM D-423 & D-424	percent	Not less than 15
Liquid limit of clay	ASTM D-2216	percent	Not less than 30
Clay particles passing	ASTM D-422	percent	Not less than 30
Clay compaction	ASTM D-2216	percent	95% of Standard Proctor Density

Source: City of Austin in Washington State, 2000

Requirements

Design (continued)

- A geotextile fabric must be used between the sand layer and drain rock or gravel and placed so that one inch of drain rock or gravel is above the fabric. Drain rock should be 1.5- to 0.75-inch rock or gravel backfill, washed free of clay and organic material.
- Cleanout wyes with caps or junction boxes must be provided at both ends of the collector pipes. Cleanouts must extend to the surface of the filter. A valve box must be provided for access to the cleanouts (see Fig. 1).

Impermeable Liners

Impermeable liners should be used when nonconventional soluble pollutants such as metals and organics are present and where the underflow could cause problems with structures or groundwater. Liners may be clay, concrete or geomembrane.

- Clay liners should have a minimum thickness of 12 inches and meet the specifications in Table 3.
- A geomembrane liner should be at least 30 mils thick and ultraviolet resistant. It should be protected from puncture, tearing and abrasion by installing geotextile fabric on the top and bottom of the geomembrane.
- Concrete liners may also be used for basins less than 1,000 square feet in area. Concrete should be 5 inches thick (Class A or better) and reinforced by steel wire mesh. The mesh should be 6 gauge wire or larger and 6- by 6-inch mesh or smaller. An “ordinary surface finish” is required. When the underlying soil is clay or has an unconfined compressive strength of 0.25 ton per square foot or less, the concrete should have a minimum 6-inch compacted aggregate base. This base must consist of either coarse sand and river stone or crushed stone or its equivalent with diameter of 0.75 to 1 inch.
- If an impermeable liner is not provided, an analysis should be made of possible adverse effects of seepage zones on groundwater and near building foundations, basements, roads, parking lots and sloping sites. Sand filters without impermeable liners should not be built on fill sites. They should be located at least 20 feet downslope and 100 feet upslope from building foundations.

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Slopes and Siting

- Include an access ramp with a slope not to exceed 7:1 or equivalent for maintenance purposes at the inlet and the outlet of a surface filter.
- Side slopes for earthen or grass embankments should not exceed 3:1 (horizontal:vertical) to facilitate mowing.
- Some designs may require perimeter fencing to reduce safety hazards.
- High groundwater may damage underground structures or affect the performance of filter underdrain systems. There should be sufficient clearance (at least 2 feet is recommended) between the seasonal high groundwater level (highest level of groundwater observed) and the bottom of the BMP to obtain adequate drainage.
- Maximum longevity of the sand filter may be achievable by limiting its use only to impervious areas.

Sequencing

- Care should be taken during construction to minimize the risk of premature failure of the sand filter. This failure is caused by the deposition of sediments from disturbed, unstabilized areas. This can be minimized or avoided by proper sequencing.
- Ideally, construction of the sand filters should take place after the site has been stabilized.
- Diversion berms should be maintained around the perimeter of the sand filters during all phases of construction. Sediment and erosion controls should be used to keep runoff and sediment away from the sand filter. Sand filters should not be used as temporary sediment traps included for construction activities.
- No runoff should enter the sand filter prior to completion of construction and the complete stabilization of the tributary areas.
- During and after excavation, all excavated materials should be placed downstream, away from the sand filters, to prevent redepositing during runoff events.

Construction

- Disturbed areas that are sediment sources in the contributing drainage area should be identified and stabilized to the maximum extent practicable.
- Where possible, excavation should be performed with backhoes rather than loaders. Heavy construction equipment should be avoided in favor of light, wide-tracked or marsh-track equipment. A light, wide-tracked, low-ground-pressure bulldozer (4 psig or less) should be used for grading.
- Overcompaction of the sand filter should be avoided to help ensure adequate filtration capacity.
- The underdrain piping must be reinforced to withstand the weight of the overburden.
- The minimum grade of the piping should be 1/8 inch per foot (approximately 1 percent slope).
- The careful selection of topsoil and sod for natural cover will help reduce the potential for failure. Sod with fine silts and clays will clog the top of the sand filter.

Surface Sand Filters

Construction

- Side slopes of earthen embankments should not exceed 3:1 (horizontal: vertical). Fencing around sand filters may be recommended for some designs to reduce safety hazards.
- Careful level placement of the sand is necessary to avoid formation of voids within the sand that could lead to short-circuiting (particularly around penetrations for underdrain cleanouts) and to prevent damage to the underlying underdrain system. Voids between the trench walls and the geotextile fabric should also be avoided.
- Consolidation of material in the sand filters during construction must be taken into consideration. The depth of the bed can be stabilized by wetting the sand periodically, allowing it to consolidate, and then adding extra sand. This should be repeated until consolidation is complete. Mechanical compaction of the sand should be avoided.
- If sediment does enter the sand bed during construction, the entire sand bed, as well as the underdrain system, must be renewed after the site is stabilized.

Maintenance

- Maintenance is required for the proper operation of sand filters. Plans for sand filters should identify owners, parties responsible for maintenance and an inspection and maintenance schedule.
- All filter system designs must provide adequate access to the filter for inspection and maintenance.
- Most filters will show some decreased effectiveness after a few years, depending mostly on the activities occurring in the drainage area.
- Sand filters should be inspected after every major storm in the first few months after construction to ensure proper function. Thereafter, the sand filter should be inspected at least once every 6 months.
- Maintenance for sand filters consists of removing the first two or three inches of discolored sand and replacing it with new sand. The removed sand should be dewatered if necessary and then landfilled.
- Sediment removal within the basin should be performed when the sediment is dry. This prevents smearing of the basin floor and allows sediment to more readily separate from the basin floor.
- Silt and sediment should be removed from the surface of the filter when an accumulation of 1 inch has occurred or when the drawdown time increases beyond 20 percent of design value.
- Removal of sediment, trash and debris should be performed with rakes if possible. If construction equipment is used, only low-ground-pressure equipment, as specified in the construction requirements section, should be allowed.
- Vegetation should be maintained as needed. Devices with healthy vegetation tend not to clog. The use of flood- and drought-resistant varieties will minimize maintenance needs. Native vegetation may be an important option for some sites. Consider using professionals familiar with plantings used specifically for these design methods.
- Sediments, trash and debris should also be removed from the pretreatment basin on a regular basis to help ensure proper performance.

Surface Sand Filters

Sources

1. Galli, J., 1990. *Peat Sand Filters: A Proposed Storm Water Management Practice for Urbanized Areas.* Metropolitan Washington Council of Governments.
2. King County Department of Natural Resources. 1998. *King County, Washington, Surface Water Design Manual.* Seattle.
3. Maryland Department of the Environment. 1998. *Maryland Stormwater Design Manual.* Baltimore.
4. Massachusetts Department of Environmental Protection. 1999. *Stormwater Management Volume Two: Stormwater Technical Handbook.* Boston.
5. Minnesota Pollution Control Agency. 2000. *Protecting Water Quality in Urban Areas: Best Management Practices for Dealing with Storm Water Runoff from Urban, Suburban and Developing Areas of Minnesota.* St. Paul.
6. North Carolina Department of Environment and Natural Resource. 1999. *Stormwater Best Management Practices.* Raleigh.
7. Ontario Ministry of the Environment. 1999. *Stormwater Management Planning and Design Manual. Draft Final Report.* Toronto.
8. Washington State Department of Ecology. 2000. S*tormwater Management Manual for Western Washington, Volume V: Runoff Treatment BMPs Final Draft.* Olympia.
9. U.S. Environmental Protection Agency. 1999. *Storm Water Management Fact Sheet.* Report numbers EPA-832-F-99-001 through EPA-843-F-99-050. Washington, D.C.