



Design Considerations

- Aesthetics
- Hydraulic Head

Targeted Constituents	Removal
Sediment	High
Nutrients	Low
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High
Flow Control	High

Description

Stormwater sand filters exist in two general design styles, surface and subsurface, often referred to as the Austin and Delaware styles (respectively). They both remove pollutants by filtering stormwater vertically through a sand media. Surface sand filters operate similarly to infiltration basins, however can be lined and incorporate an underdrain structure. Subsurface filters are two-chambered devices consisting of a pretreatment settling chamber and a filter chamber filled with sand. Subsurface filters require less space than many LID BMPs and are therefore most often incorporated in ultra-urban areas.



California Experience

Caltrans constructed and monitored five surface sand filters and one subsurface design in southern California. Pollutant removal was very similar for both designs; however operational and maintenance aspects were quite different. The subsurface filters maintain permanent pools and consequently mosquito management was a critical issue. Removal of the top few inches of sand was required at three of the surface filters and the subsurface filter during the third year of operation; consequently, sizing of the filter bed is a critical design factor for establishing maintenance frequency.

Surface sand filters have been shown to be effective at reducing many of the pollutants regulated by the State and Regional Water Boards. Additionally, the Water Boards have determined that

sand filters can qualify as a "Full Capture System (FCS)"¹ for trash. Accordingly, in addition to providing general specifications, this fact sheet includes trash-specific information to assist with upgrading either an existing BMP or the design of a planned BMP to meet the FCS definition. See the "Full Trash Capture Compliance" section and "Trash FCS" subsections in this fact sheet for more information.

Advantages

- Provides stormwater treatment and can be designed to meet hydromodification management requirements and the full capture system definition for trash control.
- Relatively high pollutant removal, especially for sediment and associated pollutants.
- Widespread application with sufficient capture can provide significant control of channel erosion.

Limitations

- Can be more expensive to construct and maintain than many other BMPs.
- Generally require more hydraulic head to operate properly (minimum 4 feet).
- Permanent pools in subsurface filters may enable mosquito and midge breeding.

Performance

Sand filters are effective stormwater management practices for pollutant removal. Conventional removal rates for all sand filters are presented in Table 1. With the exception of nitrates, which are always exported from filtering systems because of the conversion of ammonia and organic nitrogen to nitrate, they perform relatively well at removing pollutants.

Table 1. Typical pollutant removal for constituents and removal processes

Pollutant	Typical Removal	Median Effluent Concentration ¹	Removal Processes	References
Sediment	High (74% to 95%)	8.7 mg/L	Settling in pretreatment and surface, filtration and sedimentation in media.	Barrett 2003, 2008, 2010; Bell et al. 1995; Geosyntec Consultants and Wright Water Engineering 2012; Horner and Horner 1995;

¹ Full Capture System (FCS): A treatment control, or series of treatment controls, including but not limited to, a multi-benefit project or a low impact development control that traps all particles that are 5 mm or greater, and has a design treatment capacity that is either: a) of not less than the peak flow rate, Q, resulting from a one-year, one-hour, storm in the subdrainage area, or b) appropriately sized to, and designed to carry at least the same flows as, the corresponding storm drain.

Pollutant	Typical Removal	Median Effluent Concentration ¹	Removal Processes	References
Metals	High (14% to 87%)	<u>TA</u> s: 0.87µg/L, <u>TCd</u> : 0.16µg/L, <u>TCr</u> : 1.02µg/L, <u>TCu</u> : 6.01µg/L, <u>TPb</u> : 1.69µg/L, <u>TNi</u> : 2.20µg/L, <u>TZi</u> : 19.9µg/L	Removal with sediment (optional: sorption to organic matter and clay amendments in media).	Barrett 2010; Geosyntec Consultants and Wright Water Engineering 2012
Total phosphorus	Low (-14% to 69%)	0.09 mg/L	Settling with sediment (optional: sorption to organic matter and clay amendments in media). Poor removal efficiency can result from media containing high organic matter or with high background concentrations of phosphorus.	Barrett 2010; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2012;
Total nitrogen	Low (20%)	TN: 0.82 mg/L, TKN: 0.57 mg/L, <i>NO_{2,3-N}</i> : 0.51 mg/L	Sorption and setting (TKN) and denitrification in IWS (nitrate). Poor removal efficiency can result from media containing high organic matter.	Barrett 2008; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2012;
Bacteria	High (fecal coliform: -70% to 54%, Fecal streptococcus: 11% to 68%)	Fecal coliform: 542 MPN/100mL	Sedimentation, filtration, sorption, desiccation, predation, and photolysis in surface layer.	Barrett 2010; Geosyntec Consultants and Wright Water Engineering 2012
Trash	High	<u>N/A</u>	Filtration (treatment depth of 1.5 feet of media)	Barrett et al. 2013

¹ Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

In addition to the relatively high pollutant removal in sand filters, these devices, when sized to capture the channel forming storm volume, are highly effective at attenuating peak flow rates and reducing channel erosion.

In general, when contamination of groundwater with conventional pollutants is of concern, sand filters are preferred over infiltration practices, such as infiltration trenches. In most cases, sand filters can be constructed with impermeable basin or chamber bottoms, which help to collect, treat, and release runoff to a storm drainage system or directly to surface water with no contact between contaminated runoff and groundwater.

Trash FCS

The Trash Amendments adopted by the State Water Board in April 2015 provide a performance standard for treatment of stormwater for trash in the form of the definition of FCS, which surface sand filters meet (see Section 5.6.1 for FCS details).

Suitability and Design

The selection of a sand filter design depends largely on the drainage area’s characteristics. Subsurface filters typically treat runoff from drainage areas that are exclusively impervious (e.g., parking lots, loading docks, service stations, garages, airport runways/taxiways, and storage yards). Surface sand filtration systems are more suited for large drainage areas that have both impervious and pervious surfaces. This system is located at grade and is used to treat runoff from any urban land use. The constraints of the considered site dictate the appropriate style. Fundamental sand filter design and siting guidelines include:

Surface Sand Filter

- Drainage area that has been fully stabilized, plus use of a pretreatment BMP (e.g., grassed swales) at the entry point to ensure longevity.
- Geotechnical investigation required to identify soil infiltration rate. If known soil contamination is present, infiltration is not allowed.
- When infiltrating, 10 feet of separation between bottom of bed and seasonal high water table.
- Capture volume determined by local requirements and sized to treat the WQV.
- Sized to discharge the capture volume over a period of 12–48 hours.

Subsurface Sand Filter

- Sedimentation and filtration basins that are covered which are accessible to vector control personnel via access doors to facilitate vector surveillance and control.

Costs for both sand filter styles vary in accordance with the design. Table 2 details a number of core construction components and corresponding design considerations.

Table 2. Cost of design components and associated considerations

Component	Cost	Design Consideration
Excavation With underdrains	\$2.80–\$5.05/ ft ²	Surface sand filters: installed in shallow depressions on surface. Underdrain required if subsoil infiltration

Component	Cost	Design Consideration
2 feet (min) to 3 feet	\$3.90–\$6.15/ft ²	rate < 0.5 in/hr. No greater than 8 feet ponding depth (shallower depth should be used in residential areas or near schools and parks). Subsurface sand filters: can be installed along the edges of roads.
Pretreatment		Surface: Provide stabilized inlets and energy dissipation. Install rock armored forebay for concentrated flows, gravel fringe and vegetated filter strip for sheet flows to surface sand filters. For subsurface sand filters, use a sedimentation chamber.
Soil Media	\$1.90–\$5.05/ft ²	1 1.5–4 feet (deeper for better pollutant removal and hydrologic benefits). Total phosphorus composition < 15 ppm. Surface drawdown: 12–24 hrs.
Soil Media Barrier		When utilizing an underdrain, separate media from underdrain with 2 to 4 inches of washed sand (ASTM C-33), followed by 2 inches of choking stone (ASTM No. 8) over a 1.5 ft envelope of ASTM No. 57 stone.
Geotextile Washed sand (2-inch layer) No. 8 aggregate (min 2 inches thick) No. 57 stone (1.5 + feet)	\$0.45/ft ² \$0.20/ft ² \$0.28/ft ² \$2.49/ft ²	
Underdrain Pipe		4-inch diameter minimum, schedule 40 PVC pipe with perforations (slots or holes) every 6 inches at 0.5% slope. Provide cleanout ports/observation wells for each underdrain pipe.
(includes drainage stone, with 5-foot spacing)	\$3.60/ft ²	
Hydraulic Restriction Layer		If non-infiltrating, use hydraulic restriction layer. If infiltrating may use on vertical surfaces to restrict lateral flows to adjacent subgrades, foundations, or utilities.
30-mil liner	\$0.35/ft ²	
Concrete barrier	\$12.00/ft ²	

Pretreatment is a critical element of sand filter design. Surface filters can utilize rock armored forebay for concentrated flows, gravel fringe and vegetated filter strip for sheet flows. In subsurface sand filters, pretreatment is achieved in the sedimentation chamber that precedes the filter bed. Here the coarsest particles settle out and do not reach the filter bed. Pretreatment reduces the maintenance burden of sand filters by reducing the potential for these sediments to clog the filter.

Additional Design Guidelines

Many guidelines recommend sizing the filter bed using Darcy's Law, which relates the velocity of fluids to the hydraulic head and the coefficient of permeability of a medium. The resulting equation, as derived by the city of Austin, Texas, (1996), is

$$A_f = WQV d / [k t (h+d)]$$

Where:

A_f = area of the filter bed (ft²);

d = depth of the filter bed (ft; usually about 1.5 feet, depending on the design);

k = coefficient of permeability of the filtering medium (ft/day);

t = time for the water quality volume to filter through the system (days; usually assumed to be 1.67 days); and

h = average water height above the sand bed (ft; assumed to be one-half of the maximum head).

Typical values for k , are shown in Table 3.

Table 3 Coefficient of permeability values for stormwater filtering practices	
Filter Medium	Coefficient of Permeability (ft/day)
Sand	3.5-10
Compost	8.7

The permeability of sand shown in Table 3 is extremely conservative, but is widely used since it is incorporated in the design guidelines of the City of Austin. When the sand is initially installed, the permeability is so high (over 100 ft/d) that generally only a portion of the filter area is required to infiltrate the entire volume, especially in a “full sedimentation” Austin design where the capture volume is released to the filter basin over 24 hours.

The preceding methodology results in a filter bed area that is oversized when new and the entire water quality volume is filtered in less than a day with no significant height of water on top of the sand bed. Consequently, the following simple rule of thumb is adequate for sizing the filter area. If the filter is preceded by a sedimentation basin that releases the water quality volume (WQV) to the filter over 24 hours, then

$$A_f = WQV/18$$

If no pretreatment is provided then the filter area is calculated more conservatively as:

$$A_f = WQV/10$$

Typically, filtering practices are designed as “off-line” systems, meaning that during larger storms all runoff greater than the water quality volume is bypassed untreated using a flow splitter, which is a structure that directs larger flows to the storm drain system or to a stabilized channel.

A fixed vertical sediment depth marker should be installed in the sedimentation basin to indicate when 20% of the basin volume has been lost because of sediment accumulation.

Sedimentation Pond Outlet Structure: The outflow structure from the sedimentation chamber should be (1) an earthen berm; (2) a concrete wall; or (3) a rock gabion. Gabion outflow structures should extend across the full width of the facility such that no short-circuiting of flows can occur. The gabion rock should be 4 inches in diameter. The receiving end of the sand filter should be protected (splash pad, riprap, etc.) such that erosion of the sand media does not occur. When a riser pipe is used to connect the sedimentation and filtration basins (example in Figure 2), a valve should be included to isolate the sedimentation basin in case of a hazardous material spill in the watershed. The control for the valve must be accessible at all times, including when the basin is full. The riser pipe should have a minimum diameter of 6 inches with four 1-inch perforations per row. The vertical spacing between rows should be 4 inches (on centers).

Full Trash Capture Compliance

This section provides trash-specific information to assist with upgrading either an existing BMP or the design of a planned BMP to meet the FCS definition. In addition to developing and adopting the Trash Amendments, the State Water Board provides implementation information on its Trash Implementation web page:

https://www.waterboards.ca.gov/water_issues/programs/stormwater/trash_implementation.html.

The web page includes information on best management practices or Full Capture Systems, including lists of State-certified Multi-Benefit Trash Treatment Systems. So, when selecting BMPs for trash control, fact sheet users should refer to both this BMP fact sheet and the State Water Board's Trash Implementation web page.

Design Modifications to Prevent Trash Migration, Sustain Capacity, and Prevent Reduced Functionality

The surface sand filter must be configured to allow trash to enter the system and for trash to remain in the surface sand filter until it can be collected and removed. To meet the requirement, inlets must be designed to pass the peak flow produced by the one-year, one-hour design storm or the same flows as the capacity of the inlet storm drain and solids that would be retained by a 5 mm screen or mesh, must remain in the system.

Inlets

There are a multitude of inlet configurations that will allow trash to enter and be captured in a surface sand filter. An open inlet is recommended (Figure 2) to ensure that flow is routed into surface sand filters. A capture chamber is recommended for subsurface systems (Figure) that will allow smaller particles to enter the sedimentation chamber and larger gross solids to remain on top of the grate for collection.



Figure 1. Example subsurface inlet in parking lot.



Figure 2. Example surface sand filter inlet.

Pretreatment

Pretreatment is beneficial to increase and consolidate trash capture while managing maintenance requirements. Pretreatment is beneficial to increase and consolidate trash capture while managing maintenance requirements. The diversion structure and gravel pad show in Figure 2 will slow flow and allow trash and gross solids to settle out while consolidating at the edge of the surface sand filter to make it easier for maintenance crews to collect and remove.

Trash Containment

Once trash has been captured in a sand filter it must be contained so trash does not escape the sand filter. Containment may be provided by one or more of these features:

- an external design feature or up-gradient structure designed to bypass flows exceeding the region-specific one-year, one-hour storm event; or
- the BMP having sufficient capacity to trap particles from flows exceeding those generated by the one-year, one-hour storm event; or
- the BMP having sufficient capacity to treat either the design flows or volumes through media filtration or infiltration into native or amended soils; or
- use of a maximum 5 mm mesh screen on all outlets.

Maintenance

Although sand filters are generally thought of as one of the higher maintenance BMPs, a California study indicated an average of approximately 49 hours a year were required for field activities. This was less maintenance than was required by extended detention basins serving comparable sized catchments.

Mitigating clogging is the greatest concern. The rate of clogging has been related to the TSS loading on the filter bed (Urbonas, 1999); however, the data is variable. Empirical observation of sites treating urban and highway runoff indicates that clogging of the filter occurs after 2–10 years of service. Presumably, this is related to differences in the type and amount of sediment in the catchment areas of the various installations. Once clogging occurs the top 2–3 inches of filter media is removed, which restores much but not all of the lost permeability.

Table 4. Typical maintenance activities and associated costs and frequency

Frequency	Cost	Activity
Routine Maintenance (required monthly to every 2 years)		
Routine (small)	\$1.87/ft ²	Surface: <u>Remove excess sediment, trash, and debris across the surface, inlet, and outlet.</u> Check for and stabilize erosion. Subsurface: Remove accumulated material from sedimentation chamber, inspect for vector breeding.
Routine (medium)	\$0.62/ft ²	
Routine (large)	\$0.31/ft ²	
End of Life Replacement (service life of 20 years)		
Replacement (small)	\$6.46/ft ²	Excavate to the depth of soil media. Test soil for excessive soil contamination of common stormwater pollutants (e.g. metals, nutrients). Continue to remove underlying soil if pollutants exceed standard for contaminated soil. Replace with clean soil.
Replacement (medium)	\$5.21/ft ²	
Replacement (large)	\$4.90/ft ²	
Note: Small System = 500 ft ² ; Medium System = 2000 ft ² ; Large System = 4000 ft ² <u>Underlined</u> statement indicates that the activity may be required more frequently than shown in the table to meet the State Water Board maintenance criteria for Multi-Benefit Treatment Systems to be qualified as Full Capture Systems.		

Trash FCS

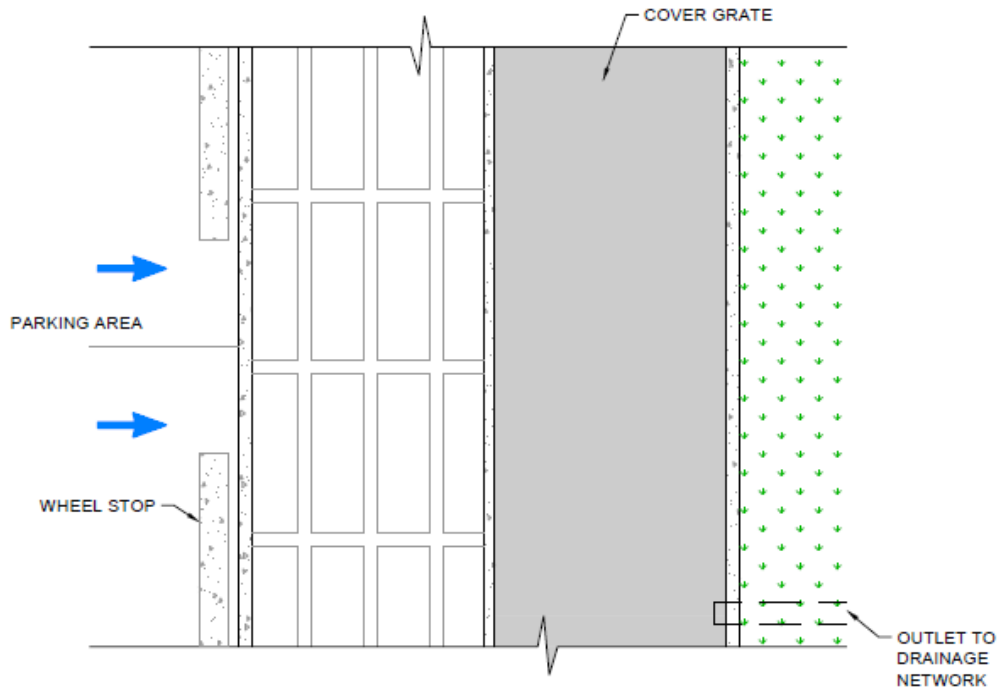
Maintenance to Prevent Trash Migration, Sustain Capacity, and Prevent Reduced Functionality

For Multi-Benefit Treatment Systems to be qualified as Full Capture Systems, the State Water Board requires regular maintenance to maintain adequate trash capture capacity and to ensure that trapped trash does not migrate offsite. Additionally, the State Water Board requires the BMP owner to establish a maintenance schedule based on site-specific factors, including the design trash capacity of the Sand Filter Multi-Benefit Trash Treatment System, storm frequency, and estimated or measured trash loading from the drainage area. To meet those criteria, it is likely that the frequency of trash and debris removal will have to be increased above the recommended monthly interval during the wet season to prevent trash from being blown from the BMP or being washed out of the surface sand filter in the subsequent rain events (see Table 4). Depending on the frequency and size of storms, and upstream pollutant characteristics, trash

and debris removal can be as frequent as before and after every wet weather event. The optimum maintenance interval can best be determined by observing the BMP in operation for a wet season.

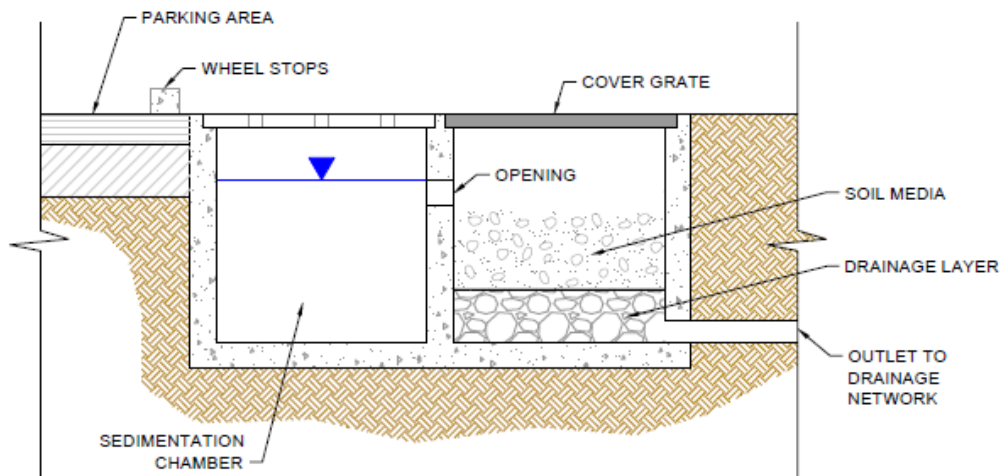
Trash maintenance not only plays a role in the functionality of the surface sand filter but also in the aesthetics and public perception of the surface sand filter (and of all BMPs). Part of maintaining positive perception among the public is the visibility of a well-maintained BMP. This positive perception can self-perpetuate further support for integrated stormwater management practices and therefore further investment in regular maintenance.

Schematic



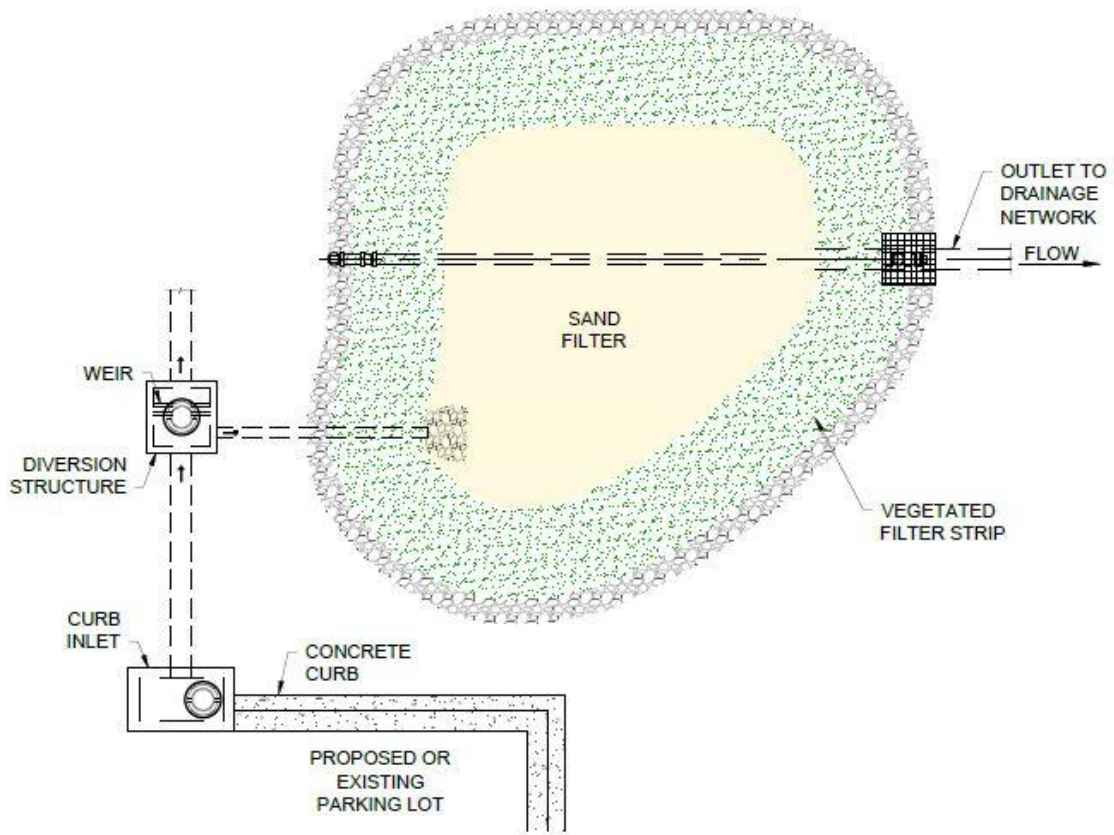
**SUBSURFACE SAND FILTER
PLAN VIEW**

NOT TO SCALE

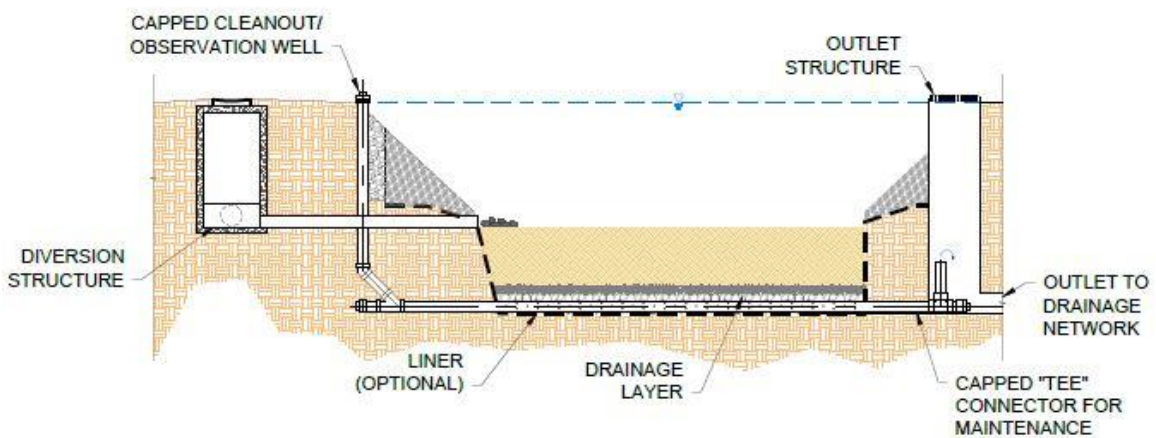


**SUBSURFACE SAND FILTER
CROSS SECTION**

NOT TO SCALE



A SAND FILTER - PLAN VIEW
- NOT TO SCALE



A SAND FILTER - SECTION
- NOT TO SCALE

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