Chapter 8 - Sand Filtration Treatment Facilities

Note: Figures in Chapter 8 are courtesy of King County, except as noted.

This Chapter presents criteria for the design, construction and maintenance of runoff treatment sand filters including basin, vault, and linear filters. Two Best Management Practices (BMPs) are discussed in this Chapter:

BMP T8.10 Sand Filter Vault
BMP T8.20 Linear Sand Filter

8.1 Purpose

To collect and treat the design runoff volume to remove TSS, phosphorous, and insoluble organics (including oils) from stormwater.

8.2 Description

A typical sand filtration system consists of a pretreatment system, flow spreader(s), a sand bed, and the underdrain piping. The sand filter bed includes a geotextile fabric between the sand bed and the bottom underdrain system.

An impermeable liner under the facility may also be needed if the filtered runoff requires additional treatment to remove soluble groundwater pollutants, or in cases where additional groundwater protection was mandated. The variations of a sand filter include a basic or large sand filter, sand filter with level spreader, sand filter vault, and linear sand filter. (Figures 8.1 through 8.7 provide examples of various sand filter configurations.)

8.3 Performance Objectives

Basic Sand Filter - Basic sand filters are expected to achieve the performance goals for Basic Treatment. Based upon experience in King County and Austin, Texas, basic sand filters should be capable of achieving the following average pollutant removals:

- 80 percent TSS at influent Event Mean Concentrations (EMCs) of 30-300 mg/L (King County, 1998) (Chang, 2000).
- Oil and grease to below 10 mg/L daily average and 15 mg/L at any time, with no ongoing or recurring visible sheen in the discharge.

Large Sand Filter ***- Large sand filters are expected to remove at least 50 percent of the total phosphorous compounds (as TP) by collecting and treating 95% of the runoff volume. (ASCE and WEF, 1998)***

8.4 Applications and Limitations

Sand filtration can be used in most residential, commercial, and industrial developments where debris, heavy sediment loads, and oils and greases will not clog or prematurely overload the sand, or where adequate pretreatment is provided for these pollutants. Specific applications include residential subdivisions, parking lots for commercial and industrial establishments, gas stations, high-use sites, high-density multi-family housing, roadways, and bridge decks.

Sand filters should be located off-line before or after detention (Chang, 2000). Sand filters are also suited for locations with space constraints in retrofit, and new/re-development situations. Overflow or bypass structures must be carefully designed to handle the larger storms. An off-line system is sized to treat 91% runoff volume predicted by a continuous runoff model. If a project must comply with Minimum Requirement #7, Flow Control, the flows bypassing the filter and the filter discharge must be routed to a retention/detention facility.

Pretreatment is necessary to reduce velocities to the sand filter and remove debris, floatables, large particulate matter, and oils. In high water table areas adequate drainage of the sand filter may require additional engineering analysis and design considerations. An underground filter should be considered in areas subject to freezing conditions. (Urbonas, 1997)

8.5 Site Suitability

The following site characteristics should be considered in siting a sand filtration system:

- Space availability, including a presettling basin.
- Sufficient hydraulic head, at least 4 feet from inlet to outlet.
- Adequate Operation and Maintenance capability including accessibility for O & M.
- Sufficient pretreatment of oil, debris and solids in the tributary runoff.

8.6 Design Criteria

Objective: To capture and treat the Water Quality Design Storm volume (when using the Simple Sizing Method described below), or 91% of the runoff volume (95% for large sand filter) predicted by a continuous runoff model, and bypass/overflow 9% of the total runoff volume to the R/D system. Off-line sand filters can be located either upstream or downstream of detention facilities. On-line sand filters should only be located downstream of detention.

***Simple Sizing Method*:** This method applies to the off-line placement of a sand filter upstream or downstream of detention facilities. A conservative design approach is provided below using a routing adjustment factor that does not require flow routing computations through the filter. An alternative simple approach for off-line placement downstream of detention facilities is to route the full 2-year release rate from the detention facility (sized for duration control) to a sand filter with sufficient surface area to infiltrate at that flow rate.

***Basic Sand Filter*:** For sizing a Basic Sand Filter, a 0.7 routing adjustment factor is applied to compensate for routing through the sand bed at the maximum pond depth. A flow splitter should be designed to route the water quality design flow rate to the sand filter. Until a continuous runoff model is available that identifies the flow rate associated with 91% of the runoff volume, use the estimate for that flow rate as identified in Chapter 4. The estimate is a percentage of the predicted 2-year return frequency flow as predicted by the Western Washington Hydrology Model. Use the adjustment for the 15-minute time series.

Large Sand Filter: For sizing a Large Sand Filter (LSF), use the same procedure as outlined above for the Basic Sand Filter. Then apply a scale-up factor of 1.6 to the surface area. This is considered a reasonable average for various impervious tributary sources. For a Large Sand Filter the flow splitter upstream or downstream of the detention facility should be designed to route the flow rate associated with conveying 95% of the runoff volume to the sand filter. Until a continuous runoff model is available that identifies the flow rate associated with conveying 95% of the runoff volume for sizing the Large Sand filter, use the water quality design flow rate for the Basic Sand Filter multiplied by 1.2.

Note: An overflow should be included in the design of the basic and large sand filter pond. The overflow height should be at the maximum hydraulic head of the pond above the sand bed.

Example Calculation using the simple sizing method and a routing adjustment factor:

Design Specifications:

Background: The sizing of the sand filter is based on routing the design runoff volume through the sand filter and using Darcy's Law to account for the increased flow through the sand bed caused by the hydraulic head variations in the pond above the sand bed. Darcy's Law is represented by the following equation:

$Q_{sf} = KiA_{sf} = FA_{sf}$	where: $i = (h+L)/L$
Therefore,	$A_{sf}=Q_{sf}/Ki$
Also,	$Q_{sf}=A_tQ_dR/t$
Substituting for Q_{sf},	$A_{sf}=A_tQ_dR/Kit$
Or,	$A_{sf}=A_tQ_dR/\{K(h+L)/L\}t$
Or,	$A_{sf}=A_tQ_dR/Ft$

Where:

Q_{sf} is the flow rate in cu. feet per day (or ft^3/sec.) at which runoff is filtered by the sand filter bed,

A_{sf} is the sand filter surface area (sq. ft.)

Q_d is the design storm runoff depth (ft.) for the 6 month, 24-hour storm. It is estimated using the SCS Curve Number equations detailed in Volume III, Chapter 2.

R is a routing adjustment factor. Use R = 0.7.

A_t is the tributary drainage area (sq. ft.)

K is the hydraulic conductivity of the sand bed. Use 2 ft./day or 1.0 inch/hour at full pre-sedimentation

i is the hydraulic gradient of the pond above the filter; (h+L)/L, (ft/ft)

F=Ki is the filtration rate, ft./day (or inches per hour)

d is the maximum sand filter pond depth, and h = d/2 in ft.

t is the recommended maximum drawdown time of 24 hours from the completion of inflow into the sand filter pond (assume ponded pre-settling basin) of a discrete storm event to the completion of outflow from the sand filter underdrain of that same storm event.

L is the sand bed depth; Use 1.5 ft.

Given condition:

- Sedimentation basin fully ponded and no pond water above sand filter (Full sedimentation prior to sand filter-24 hours residence of WQ storm runoff)
- A_t = 10 acres is tributary drainage area
- Q_d = 0.922 inches (0.0768 ft.), for SeaTac Rainfall
- with Curve Number = 96.2 for 85% impervious and 15% till grass tributary surfaces
- R = 0.7, the routing adjustment factor
- Maximum drawdown time through sand filter, 24 hours
- Maximum pond depth above sand filter, example at 3 and 6 feet,
- h = 1.5 and 3 feet
- Design Hydraulic Conductivity of basic sand filter, K, 2.0 feet/day (1 inch/hour)

Using Design Equation:

$A_{sf} = A_t Q_d RL/Kt(h+L)$

At pond depth of 6 feet:
A_{sf} = (10)43560(0.0768)(.7)(1.5)/(2)(1)(4.5) = 3911 square feet

Therefore A_{sf} for Basic Sand Filter becomes:

3911 sq. feet at pond depth of 6 feet
5867 sq. feet at pond depth of 3 feet

Using the 1.6 scale-up factor, the Large Sand Filter design sizes for the conditions of this example become:

6258 sq. feet at pond depth of 6 feet
9387 sq. feet at pond depth of 3 feet

Continuous Runoff Model Sizing Method:

Basic Sand Filter: This method is intended to capture and treat 91% of the runoff volume through use of a continuous runoff model coupled with a flow-routing routine that determines stage-storage-discharge relationships. At the time of publication of this manual, a 15-minute time series and a flow routing routine for sizing sand filters is not available with the Western Washington Hydrology Model (WWHM). Until a 15-minute time series is available, the 1-hour time series in the WWHM can be used for facility sizing. A spreadsheet must be used to calculate filtration rates as a function of head and surface area. A stage-storage-discharge table can be imported to the WWHM as an electronic text file, or, the table can be typed directly into the WWHM. The WWHM will route the post-development stormwater runoff through the stage-storage-discharge table. A spreadsheet analysis of the flow duration table produced by the WWHM can determine the total quantities discharged and bypassed for verifying that 91% of the runoff volume has been treated.

Off-line: An off-line, basic sand filter located upstream of detention facilities should have an upstream flow splitter that is designed to bypass the incremental portion of flows above the water quality design flow rate (using 15-minute time steps). The long-term runoff time series used as input to the sand filter should be modified to use the water quality design flow rate for all flows above that rate. The design overflow volume for off-line sand filters is zero since all flows routed to the filter will be at or below the water quality design flow. Therefore, the goal is to size the storage reservoir such that its capacity is not exceeded (Note: an emergency overflow should still be included in the design).

Unfortunately, at the time of publication of this manual, the user does not have access to the runoff time series to modify it as described above for design of off-line facilities. Until that capability is provided to the user, the storage reservoir for the off-line facility can be sized as if in an on-line mode. All of the post-development time series is routed to the storage reservoir, which is then sized to overflow 9% of the total runoff volume of the time series. In actual practice, an offline flow splitter will not route all of the post-development time series to the storage reservoir, and so the reservoir should not overflow if operating within design criteria. This design approach should result in slightly oversizing the storage reservoir.

Downstream of detention facilities, the flow splitter should be designed to bypass the incremental portion of flows above the flow rate that corresponds with treating 91% of the runoff volume of the long-term time series. Because the flows are dampened by the detention facility, this flow rate will be lower than the water quality design flow rate for facilities located upstream of detention. Accordingly, the post-detention runoff time series, used as input to the filter, should be adjusted to use the flow rate corresponding to treating 91% of the runoff volume for all flows above that rate. Note: Downstream of detention facilities, a one-hour time series may be used to compute the sand filter size until such time as a 15-minute time series is available. Due to the flow dampening effect of the detention facilities, there should not be much difference between a sand filter sized to treat 91% of the runoff volume using 15-minute versus 1-hour time series data.

On-line: Sand filter designs that are on-line (i.e., all flows enter the storage reservoir) should only be allowed downstream of detention facilities to prevent exposure of the sand filter surface to high flow rates that could cause loss of media and previously removed pollutants. The storage pond above the sand bed should be sized to restrict the total amount of overflow from the reservoir to 9% of the total runoff volume of the long-term time series.

Large Sand Filter: This method is intended to capture and treat 95% of the runoff volume through use of a continuous runoff model coupled with a flow-routing routine that determines stage-storage-discharge relationships.

Off-line: An off-line, large sand filter should have an upstream flow splitter that is designed to bypass the incremental portion of flows above the flow rate that corresponds with treating 95% of the runoff volume of the long-term time series (using 15-minute time steps). The design overflow volume for off-line sand filters is zero since all flows routed to the filter must be treated. Therefore, the goal is to size the storage reservoir such that its capacity is not exceeded (Note: An emergency overflow should still be included in the design). Because of the flow dampening effects of a detention facility, a large sand filter downstream of detention facilities will be smaller than a filter upstream of detention. A conservative design would use a flow splitter to route the full 2-year release rate from the detention facility, sized for flow duration control, to a filter with sufficient surface area to infiltrate at that flow rate. Such a design should treat over 95% of the runoff volume.

On-line: Sand filter designs that are on-line (i.e., all flows enter the storage reservoir) should only be allowed downstream of detention facilities to prevent exposure of the sand filter surface to high flow rates that could cause loss of media and previously removed pollutants. The storage pond should be sized to restrict the total amount of overflow from the reservoir to 5% of the total runoff volume of the long-term time series. This is not a preferred design because of the extended timeframe during which the filter is saturated. This will reduce its potential for phosphorus removal.

Additional Design Information:

1. Runoff to be treated by the sand filter must be pretreated (e.g., presettling basin, etc. depending on pollutants) to remove debris and other solids, and oil from high use sites.

2. Inlet bypass and flow spreading structures (e.g., flow spreaders, weirs or multiple orifice openings) should be designed to capture the applicable design flow rate, minimize turbulence and to spread the flow uniformly across the surface of the sand filter. Stone riprap or other energy dissipation devices should be installed to prevent gouging of the sand medium and to promote uniform flow. Include emergency spillway or overflow structures (see Volume III).

3. The following are design criteria for the underdrain piping: *(types of underdrains include a central collector pipe with lateral feeder pipes; or a geotextile drain strip in an 8-inch gravel backfill or drain rock bed; or longitudinal pipes in an 8-inch gravel backfill or drain rock with a collector pipe at the outlet end.)*

   - Upstream of detention, underdrain piping should be sized to handle double the two-year return frequency flow indicated by the WWHM (the doubling factor is a conversion from the 1-hr. time step to a 15 minute time step). Downstream of detention the underdrain piping should be sized for the two-year return frequency flow indicated by the WWHM. In both instances there should be at least one foot of hydraulic head above the invert of the upstream end of the collector pipe. (King County, 1998)

   - Internal diameters of underdrain pipes should be a minimum of six inches having two rows of ½-inch holes spaced 6 inches apart longitudinally (maximum), with rows 120 degrees apart (laid with holes downward). Maximum perpendicular distance between two feeder pipes must be 15 feet. All piping is to be schedule 40 PVC or greater wall thickness. Drain piping could be installed in basin and trench configurations.

   - Main collector underdrain pipe should be at a slope of 0.5 percent minimum. (King County, 1998)

   - A geotextile fabric (specifications in Appendix V-C) must be used between the sand layer and drain rock or gravel and placed so that 1-inch of drain rock/gravel is above the fabric. Drain rock should be 0.75-1.5 inch rock or gravel backfill, washed free of clay and organic material. (King County, 1998)

   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. Access for cleaning all underdrain piping should be provided. This may consist of installing cleanout ports, which tee into the underdrain system and surface above the top of the sand bed. To facilitate maintenance of the sand filter an inlet shutoff/bypass valve is recommended.

Note: Other equivalent energy dissipaters can be used if needed.

4. Sand specification: The sand in a filter must consist of a medium sand meeting the size gradation (by weight) given in Table 8.1 below. The contractor must obtain a grain size analysis from the supplier to certify that the No. 100 and No. 200 sieve requirements are met. *(Note: Standard backfill for sand drains, Wa. Std. Spec. 9-03.13, does not meet this specification and should not be used for sand filters.)*

5. Impermeable Liners for Sand Bed Bottom: Impermeable liners are generally required for soluble pollutants such as metals and toxic organics and where the underflow could cause problems with structures. Impermeable liners may be clay, concrete or geomembrane. Clay liners should have a minimum thickness of 12 inches and meet the specifications give in Table 8.2:

   - If a geomembrane liner is used it should have a minimum thickness of 30 mils and be ultraviolet resistant. The geomembrane liner 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 sedimentation chambers and for sedimentation and sand filtration basins less than 1,000 square feet in area. Concrete should be 5 inches thick Class A or better and should be reinforced by steel wire mesh. The steel wire mesh should be 6 gauge wire or larger and 6-inch 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 coarse sand and river stone, crushed stone or equivalent with diameter of 0.75- to 1-inch.
   - If an impermeable liner is not required then a geotextile fabric liner should be installed that retains the sand and meets the specifications listed in Appendix V-C unless the basin has been excavated to bedrock.
   - If an impermeable liner is not provided, then 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 and should be located at least 20-feet downslope and 100-feet upslope from building foundations.

6. 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. Consider an access port for inspection and maintenance.

7. Side slopes for earthen/grass embankments should not exceed 3:1 to facilitate mowing.

8. 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 ground water observed) and the bottom of the sand filter to obtain adequate drainage.

8.7 Construction Criteria

No runoff should enter the sand filter prior to completion of construction and approval of site stabilization by the responsible inspector. Construction runoff may be routed to a pretreatment sedimentation facility, but discharge from sedimentation facilities should by-pass downstream sand filters. 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 geomembranes and underdrain system. Over-compaction should be avoided to ensure adequate filtration capacity. Sand is best placed with a low ground pressure bulldozer (4 psig or less). After the sand layer is placed water settling is recommended. Flood the sand with 10-15 gallons of water per cubic foot of sand.

8.8 Maintenance Criteria

Inspections of sand filters and pretreatment systems should be conducted every 6 months and after storm events as needed during the first year of operation, and annually thereafter if filter performs as designed. Repairs should be performed as necessary. Suggestions for maintenance include:

- Accumulated silt and debris on top of the sand filter should be removed when their depth exceeds 1/2-inch. The silt should be scraped off during dry periods with steel rakes or other devices. Once sediment is removed, the design permeability of the filtration media can typically be restored by then striating the surface layer of the media. Finer sediments that have penetrated deeper into the filtration media can reduce the permeability to unacceptable levels, necessitating replacement of some or all of the sand.
- Sand replacement frequency is not well established and will depend on suspended solids levels entering the filter (the effectiveness of the pretreatment BMP can be a significant factor).
- Frequent overflow into the spillway or overflow structure or slow drawdown are indicators of plugging problems. A sand filter should empty in 24 hours following a storm event (24 hours for the pre-settling chamber), depending on pond depth. If the hydraulic conductivity drops to 1-inch per hour corrective action is needed, e.g.:
  - Scraping the top layer of fine-grain sediment accumulation (mid-winter scraping is suggested)

  - Removal of thatch
  - Aerating the filter surface
  - Tilling the filter surface (late-summer rototilling is suggested)
  - Replacing the top 4 inches of sand.
  - Inspecting geotextiles for clogging

- Rapid drawdown in the sand bed (greater than 12 inches per hour) indicates short-circuiting of the filter. Inspect the cleanouts on the underdrain pipes and along the base of the embankment for leakage.
- Drawdown tests for the sand bed could be conducted, as needed, during the wet season. These tests can be conducted by allowing the filter to fill (or partially fill) during a storm event, then measuring the decline in water level over a 4-8 hour period. An inlet and an underdrain outlet valve would be necessary to conduct such a test.
- Formation of rills and gullies on the surface of the filter indicates improper function of the inlet flow spreader, or poor sand compaction. Check for accumulation of debris on or in the flow spreader and refill rills and gullies with sand.
- Avoid driving heavy equipment on the filter to prevent compaction and rut formation.

BMP T8.10 Sand Filter Vault

Description: (Figures 8.6a and 8.6b)

A sand filter vault is similar to an open sand filter except that the sand layer and underdrains are installed below grade in a vault. It consists of presettling and sand filtration cells.

Applications and Limitations

- Use where space limitations preclude above ground facilities
- Not suitable where high water table and heavy sediment loads are expected
- An elevation difference of 4 feet between inlet and outlet is needed

Additional Design Criteria for Vaults

- Vaults may be designed as off-line systems or on-line for small drainages.
- In an off-line system a diversion structure should be installed to divert the design flow rate into the sediment chamber and bypass the remaining flow to detention/retention (if necessary to meet Minimum Requirement #7), or to surface water.
- Optimize sand inlet flow distribution with minimal sand bed disturbance. A maximum of 8-inch distance between the top of the spreader and the top of the sand bed is suggested. Flows may enter the sand bed by spilling over the top of the wall into a flow spreader pad or alternatively a pipe and manifold system may be used. Any pipe and manifold system must retain the required dead storage volume in the first cell, minimize turbulence, and be readily maintainable.
- If an inlet pipe and manifold system is used, the minimum pipe size should be 8 inches. Multiple inlets are recommended to minimize turbulence and reduce local flow velocities.
- Erosion protection must be provided along the first foot of the sand bed adjacent to the spreader. Geotextile fabric secured on the surface of the sand bed, or equivalent method, may be used.
- The filter bed should consist of a sand top layer, and a geotextile fabric second layer with an underdrain system.
- Design the presettling cell for sediment collection and removal. A V-shaped bottom, removable bottom panels, or equivalent sludge handling system should be used. One-foot of sediment storage in the presettling cell must be provided.
- The pre-settling chamber must be sealed to trap oil and trash. This chamber is usually connected to the sand filtration chamber through an invert elbow to protect the filter surface from oil and trash.

- If a retaining baffle is necessary for oil/floatables in the presettling cell, it must extend at least one foot above to one foot below the design flow water level. Provision for the passage of flows in the event of plugging must be provided. Access opening and ladder must be provided on both sides of the baffle.
- To prevent anoxic conditions, a minimum of 24 square feet of ventilation grate should be provided for each 250 square feet of sand bed surface area. For sufficient distribution of airflow across the sand bed, grates may be located in one area if the sand filter is small, but placement at each end is preferred. Small grates may also be dispersed over the entire sand bed area.
- Provision for access is the same as for wet vaults. Removable panels must be provided over the entire sand bed.
- Sand filter vaults must conform to the materials and structural suitability criteria specified for wet vaults.
- Provide a sand filter inlet shutoff/bypass valve for maintenance
- A geotextile fabric over the entire sand bed may be installed that is flexible, highly permeable, three-dimensional matrix, and adequately secured. This is useful in trapping trash and litter.

BMP T8.20 Linear Sand Filter

Description: (Figure 8.7)

Linear sand filters are typically long, shallow, two-celled, rectangular vaults. The first cell is designed for settling coarse particles, and the second cell contains the sand bed. Stormwater flows into the second cell via a weir section that also functions as a flow spreader.

Application and Limitations

- Applicable in long narrow spaces such as the perimeter of a paved surface.
- As a part of a treatment train as downstream of a filter strip, upstream of an infiltration system, or upstream of a wet pond or a biofilter for oil control.
- To treat small drainages (less than 2 acres of impervious area).
- To treat runoff from high-use sites for TSS and oil/grease removal, if applicable.

Additional Design Criteria for Linear Sand Filters

- The two cells should be divided by a divider wall that is level and extends a minimum of 12 inches above the sand bed.
- Stormwater may enter the sediment cell by sheet flow or a piped inlet.
- The width of the sand cell must be 1-foot minimum to 15 feet maximum.
- The sand filter bed must be a minimum of 12 inches deep and have an 8-inch layer of drain rock with perforated drainpipe beneath the sand layer.
- The drainpipe must be 6-inch diameter minimum and be wrapped in geotextile and sloped a minimum of 0.5 percent.
- Maximum sand bed ponding depth: 1-foot.
- Must be vented as for sand filter vaults.
- Linear sand filters must conform to the materials and structural suitability criteria specified for wet vaults.
- Set sediment cell width as follows:

Sand filter width, (w) inches	12-24	24-48	48-72	72+
Sediment cell width, inches	12	18	24	w/3

Table 8.1 -- 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 Surface Water Design Manual, September 1998

Table 8.2 - Clay Liner Specifications			
Property	**Test Method**	**Unit**	**Specification**
Permeability	ASTM D-2434	cm/sec	1 x 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, 1988

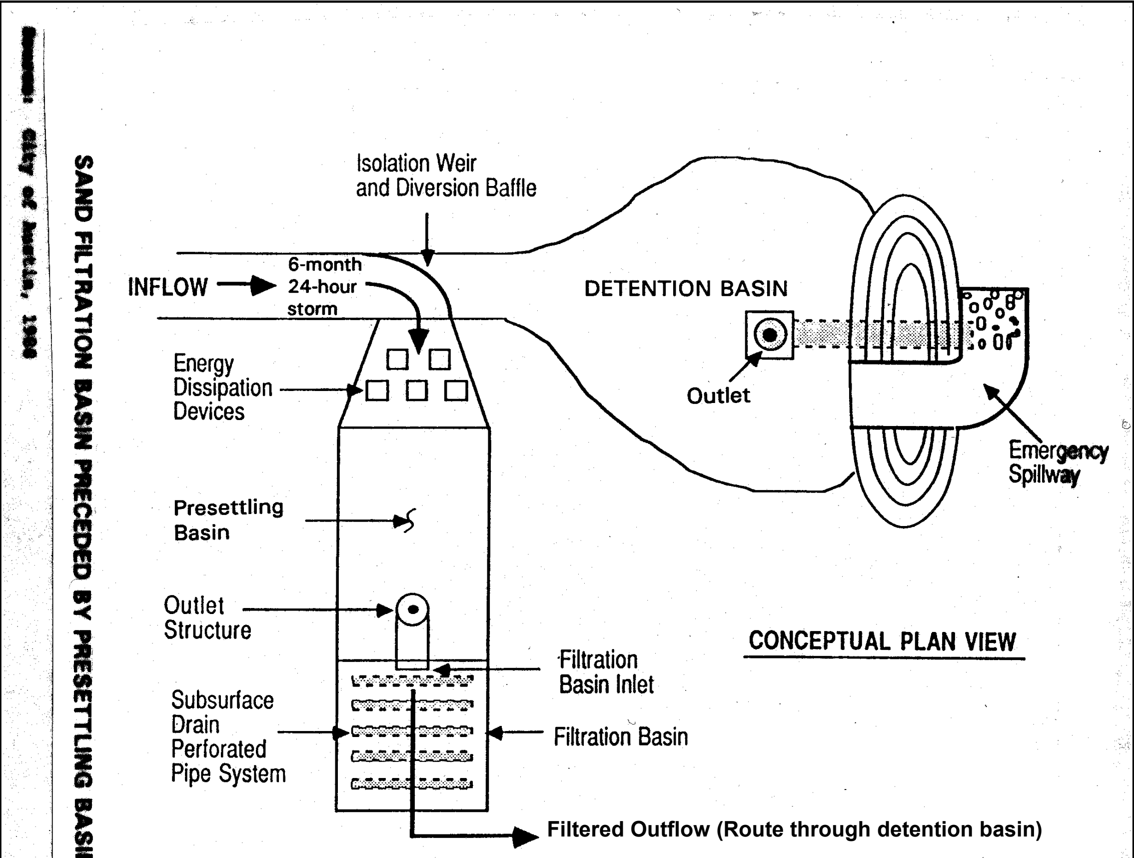


Figure 8-1 Sand Filtration Basin Preceded by Presettling Basin (Variation of a Basic Sand Filter)

Source: City of Austin

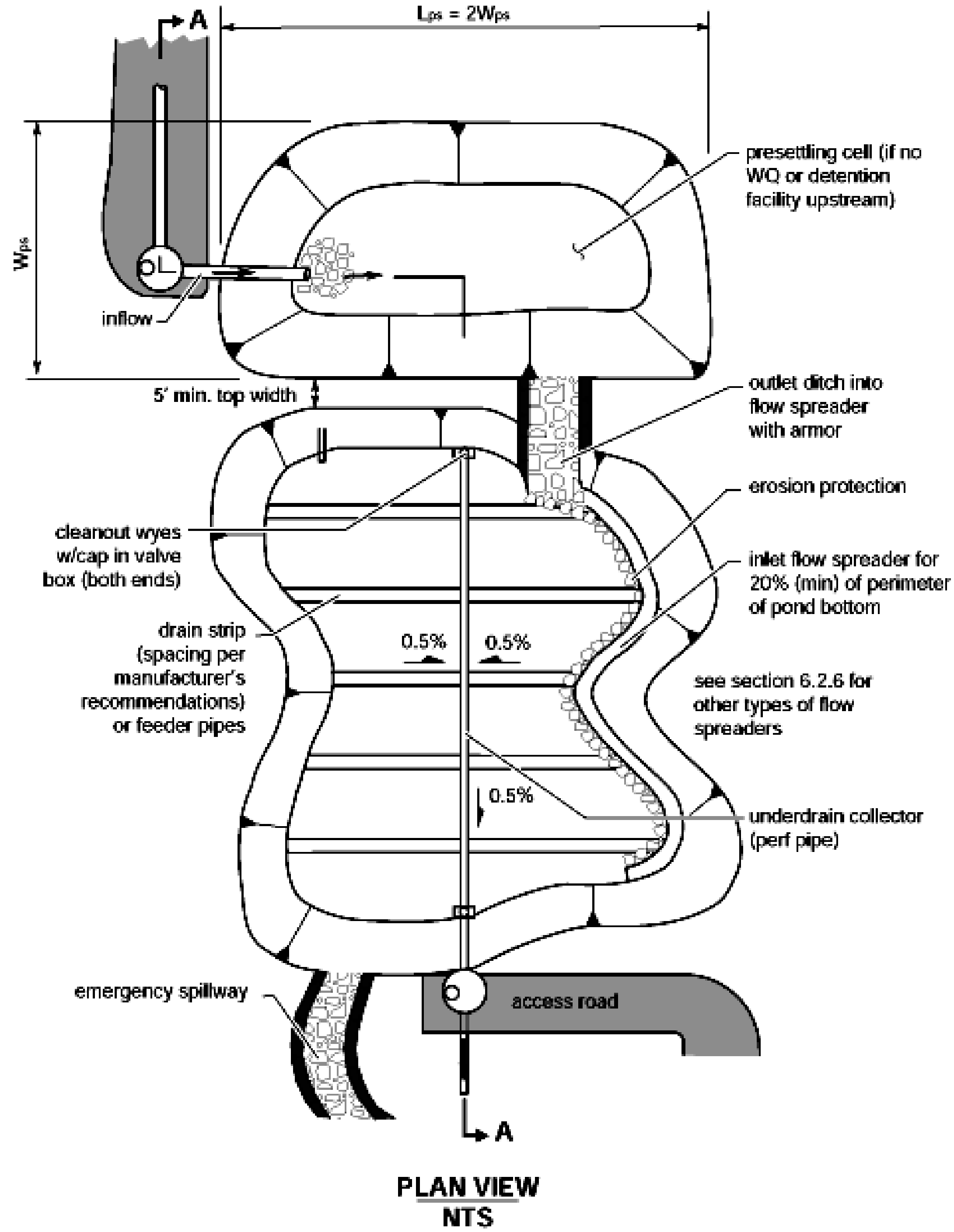


Figure 8-2 Sand Filter with Pretreatment Cell

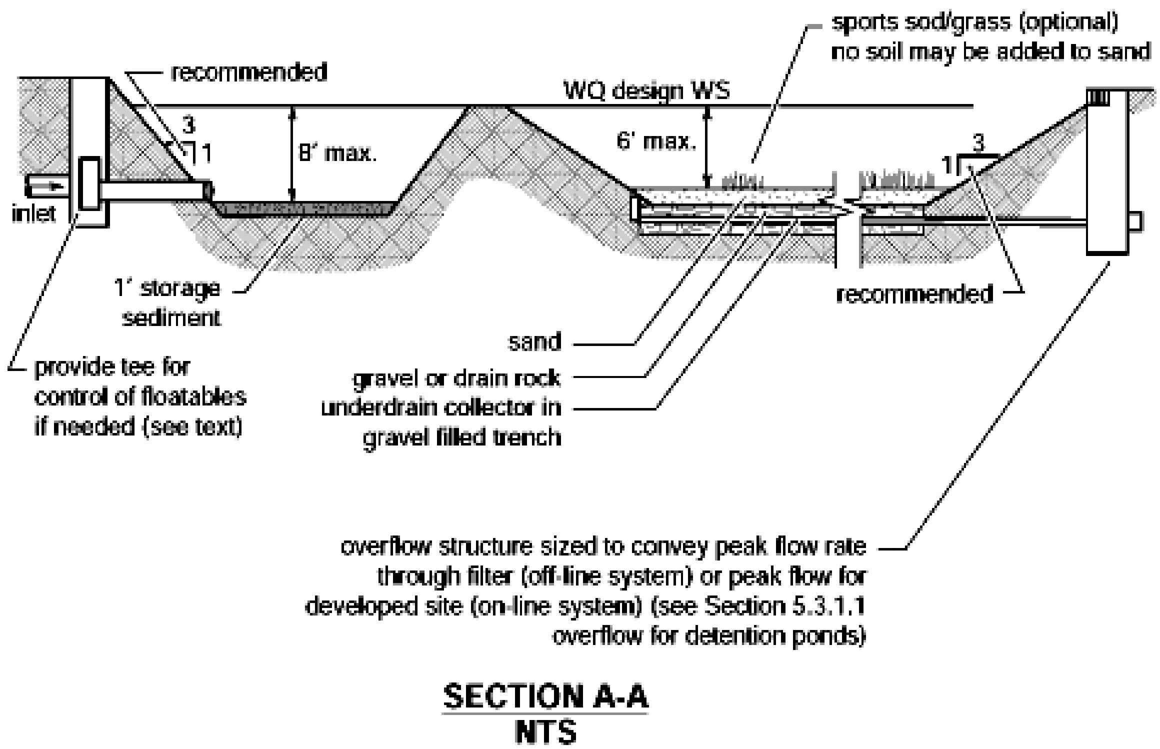


Figure 8-2 (cont) Sand Filter with Pretreatment Cell

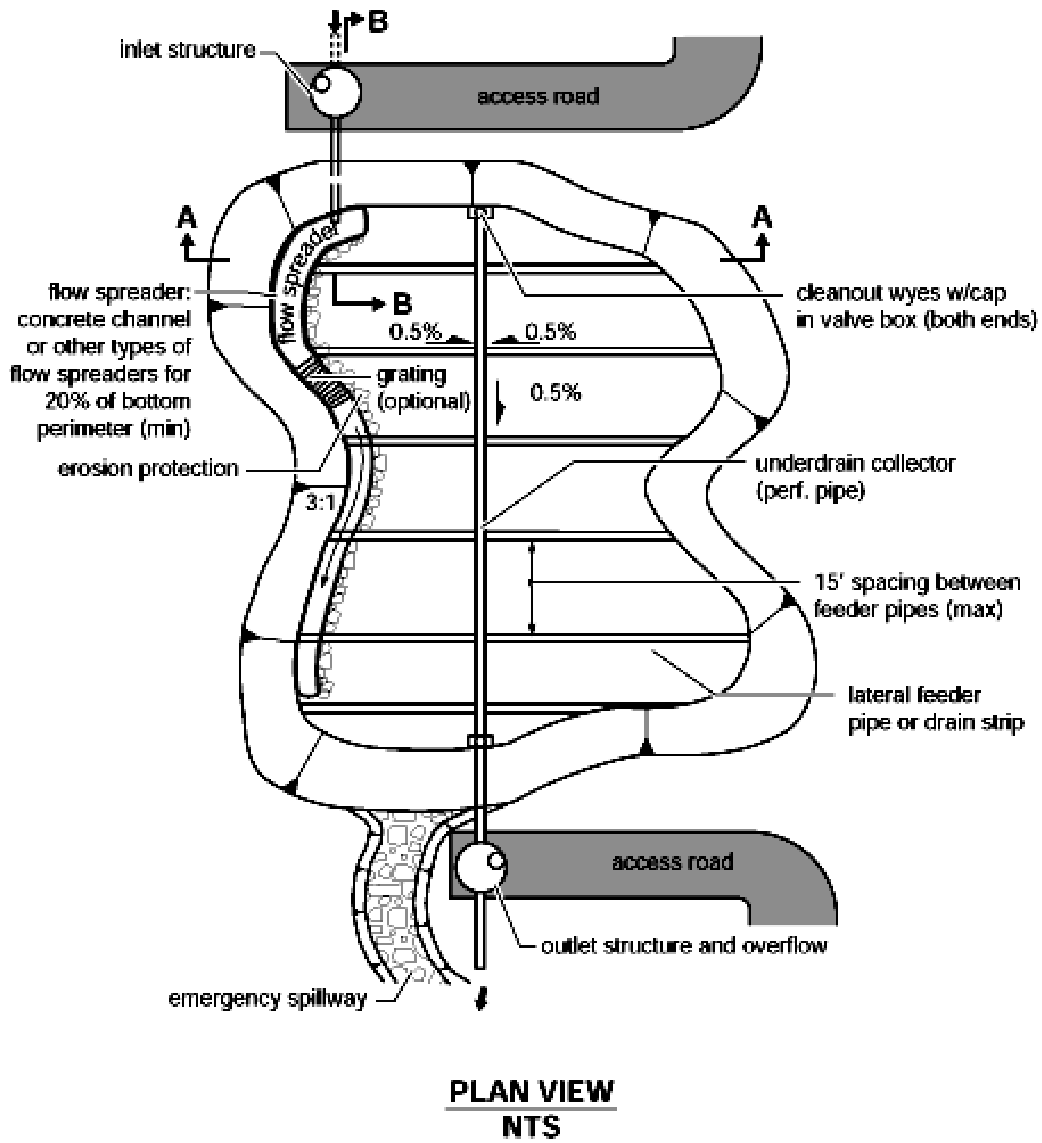


Figure 8-3 Sand Filter with Level Spreader

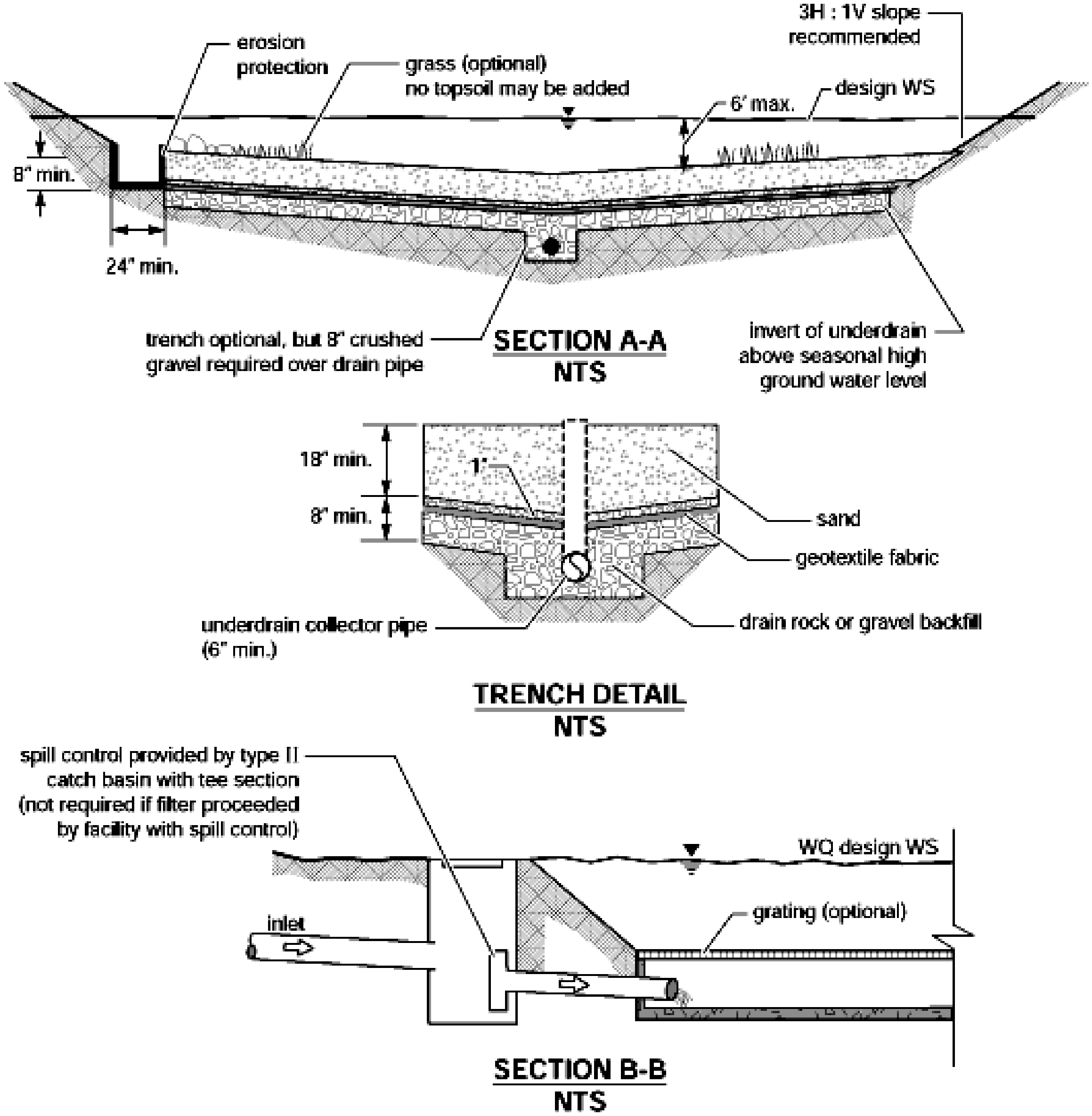
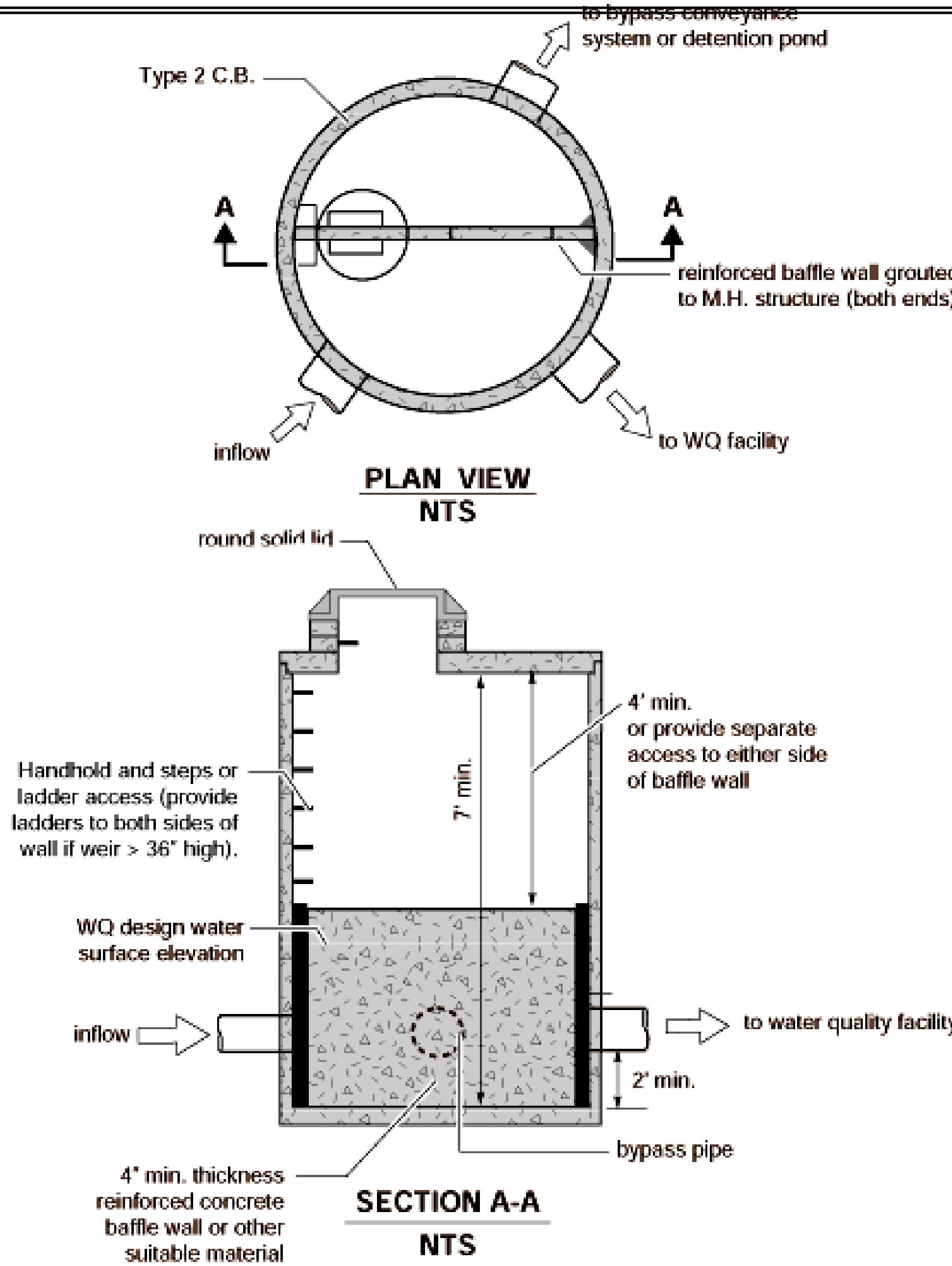
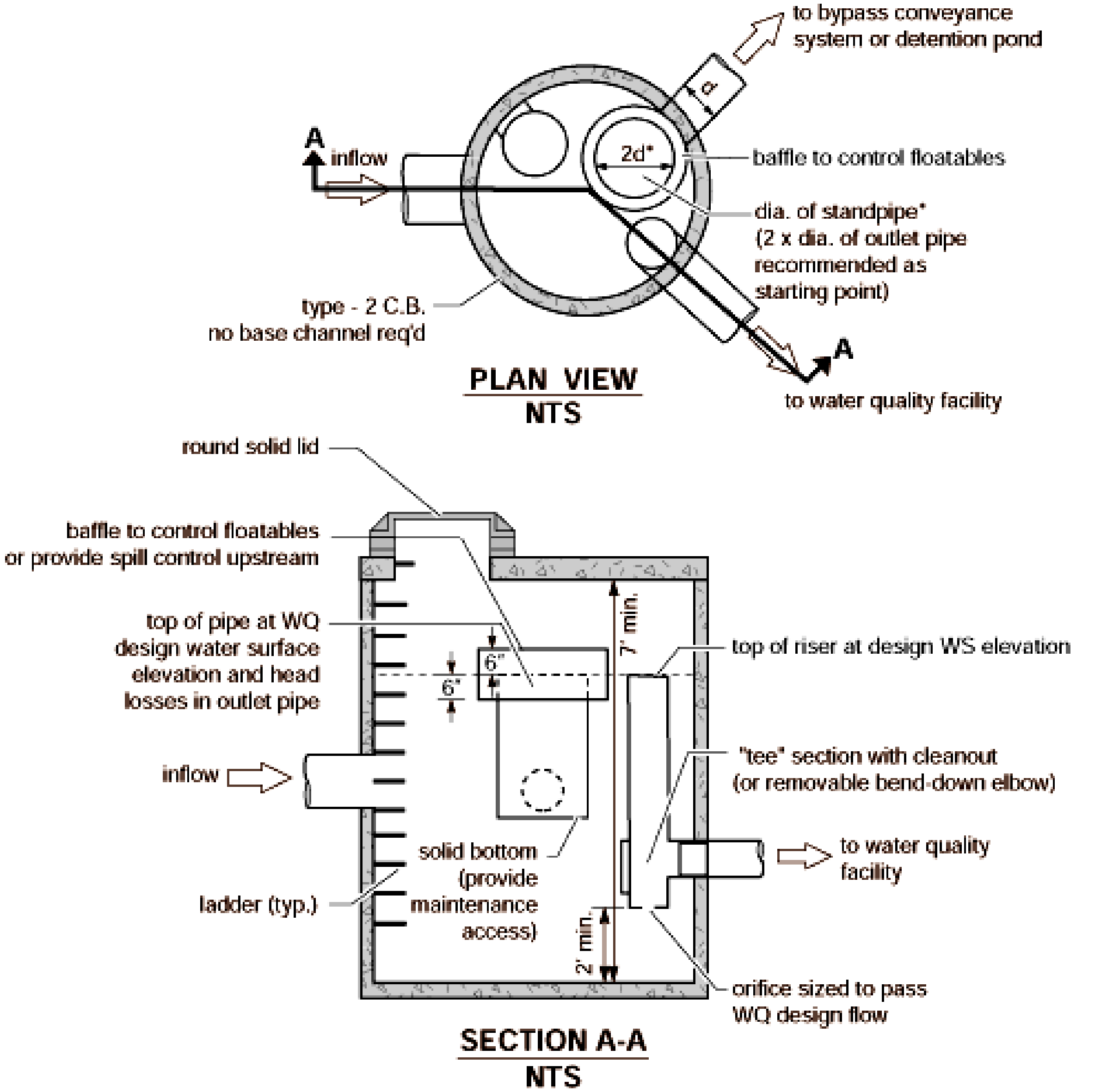


Figure 8-3 (cont) Sand Filter with Level Spreader



Note: The water quality discharge pipe may require an orifice plate be installed on the outlet to control the height of the design water surface (weir height). The design water surface should be set to provide a minimun headwater/diameter ratio of 2.0 on the outlet pipe.

Figure 8-4a Flow Splitter Option A



*NOTE: Diameter (d) of standpipe should be large enough to minimize head above WQ design WS and to keep WQ design flows from increasing more than 10% during 100-year flows.

Figure 8-4b Flow Splitter Option B

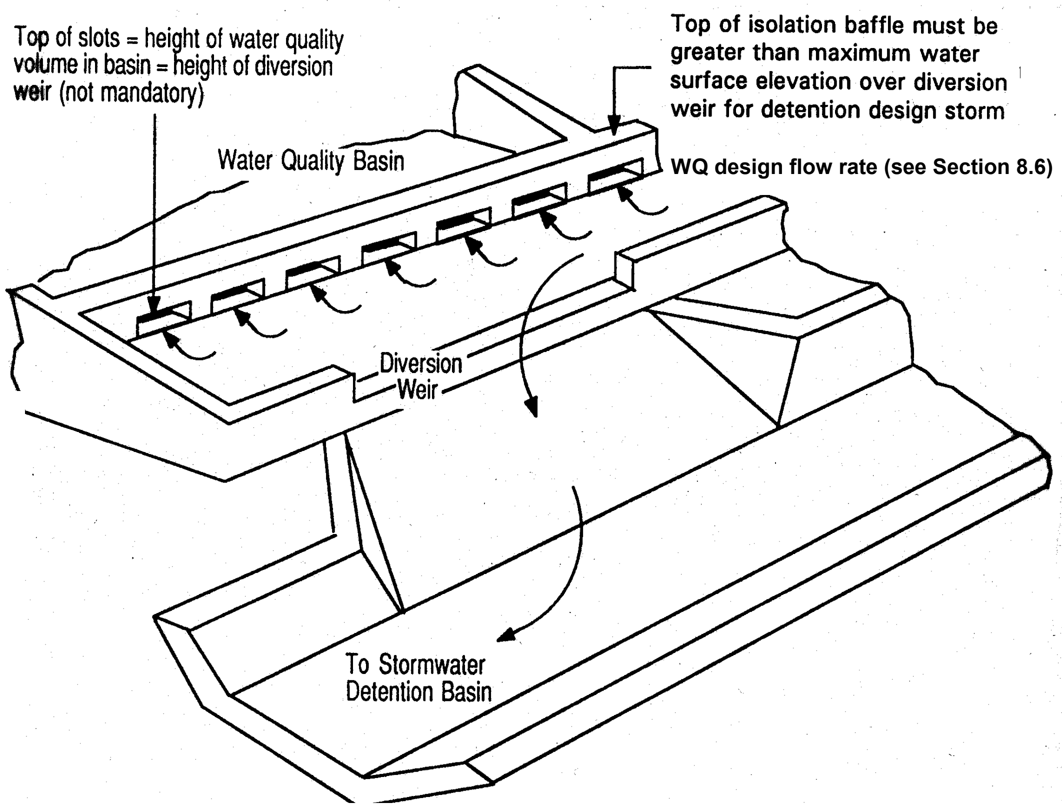


Figure 8-5 Example Isolation/Diversion Structure Source: City of Austin

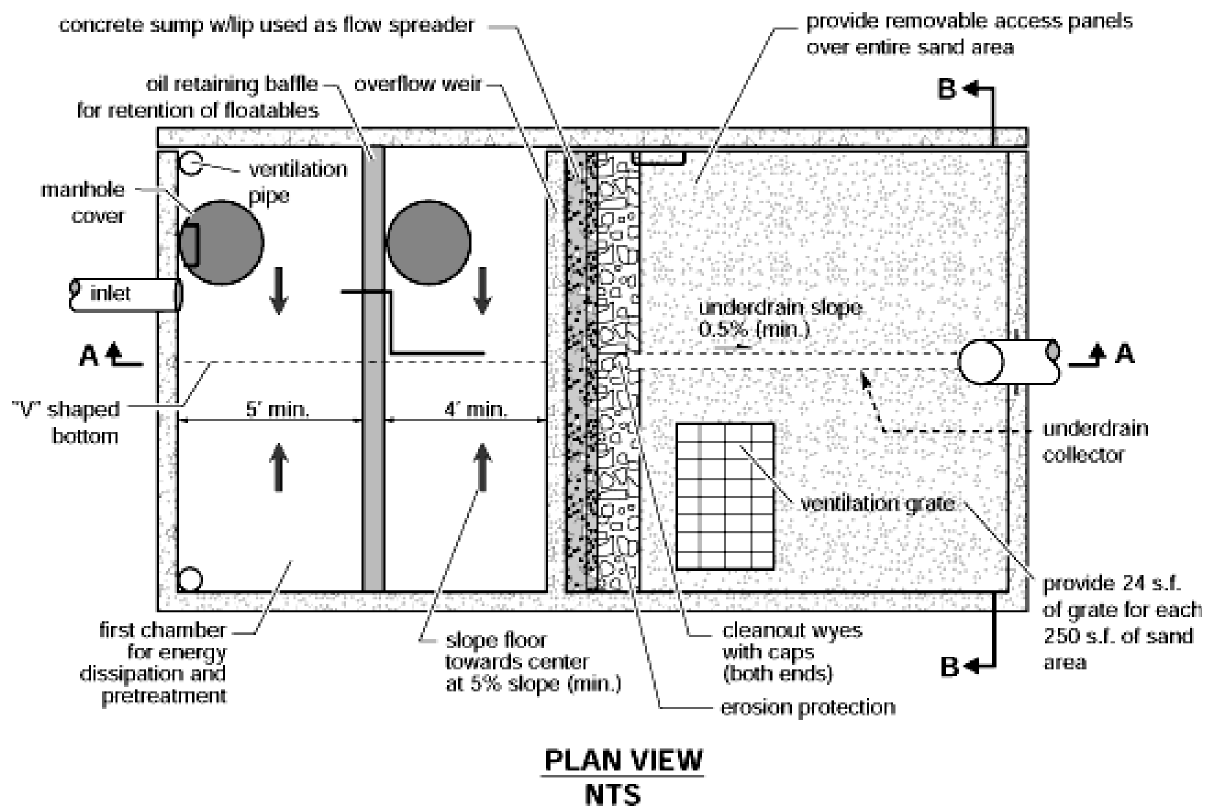
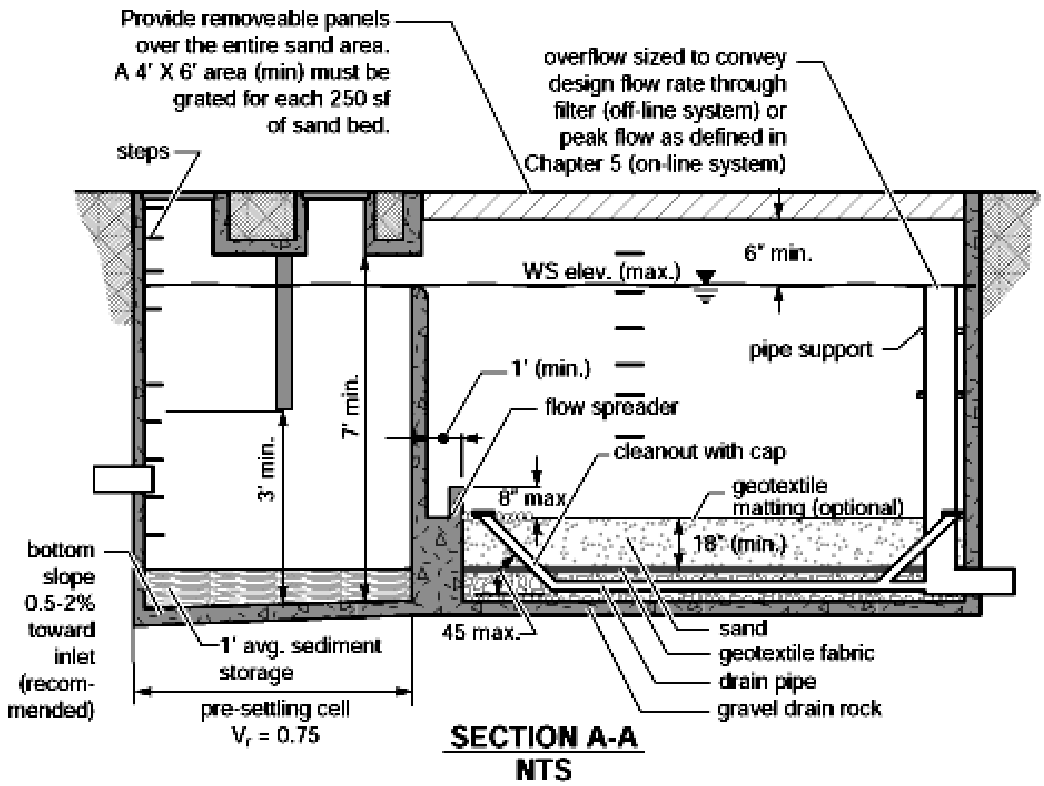


Figure 8-6a Sand Filter Vault



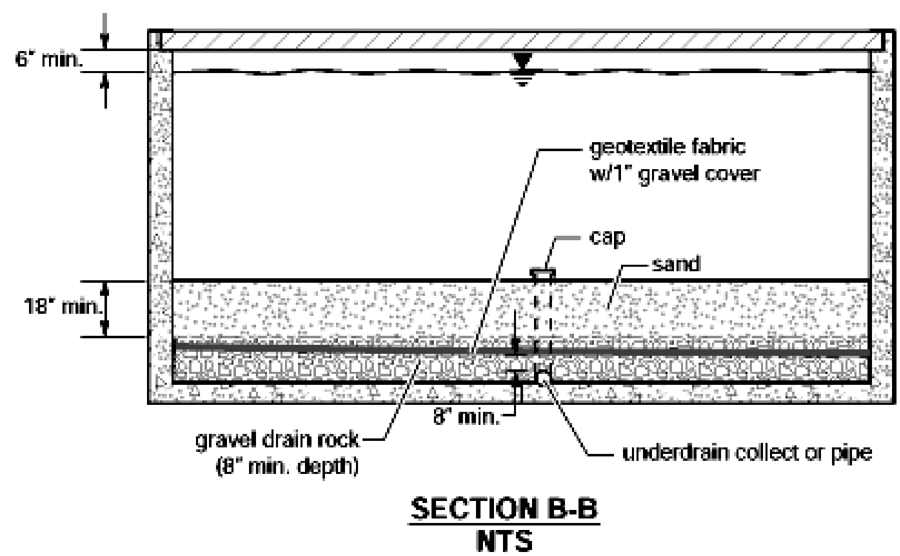


Figure 8-6b Sand Filter Vault (cont)

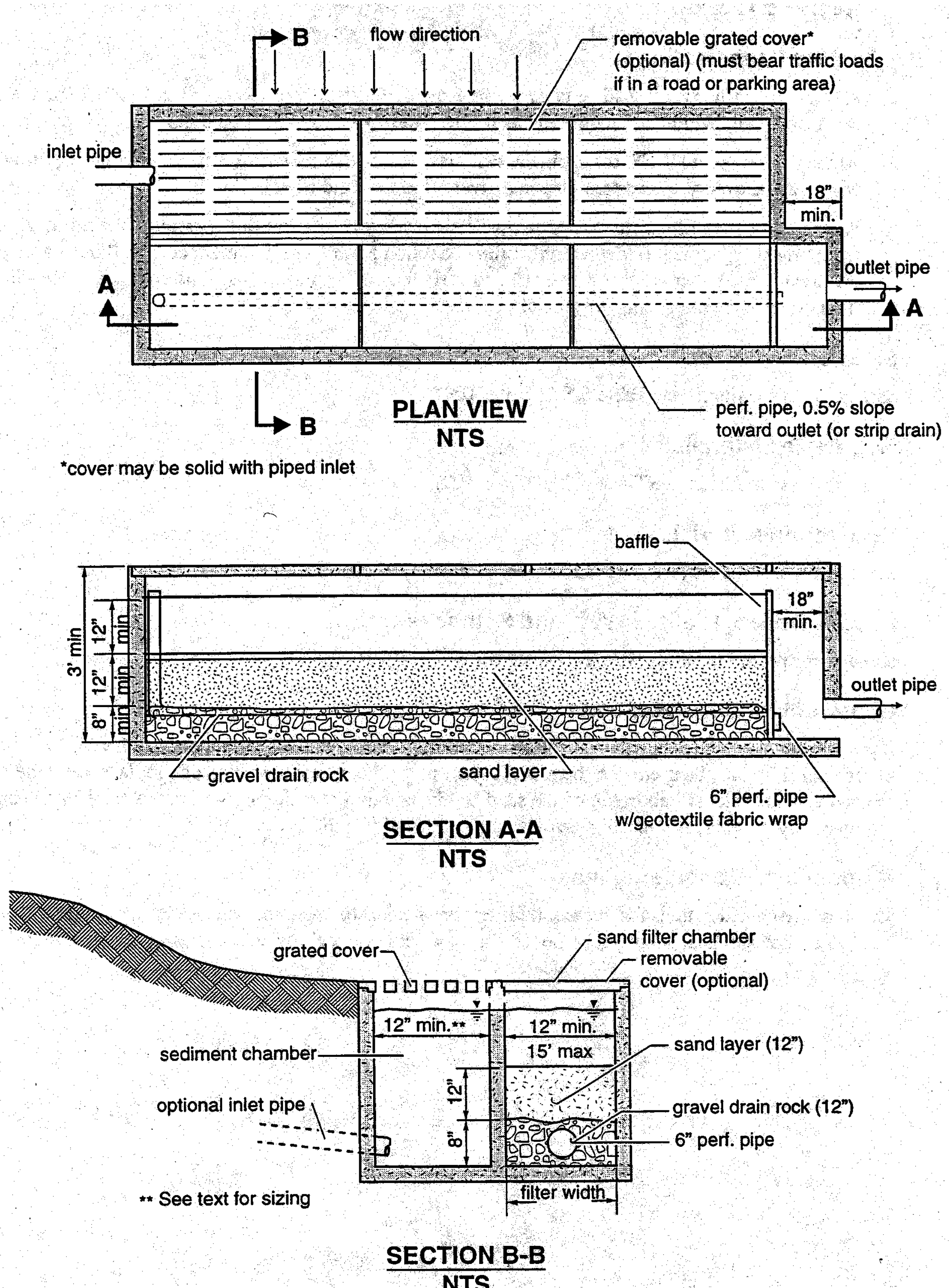


Figure 8-7 Linear Sand Filter