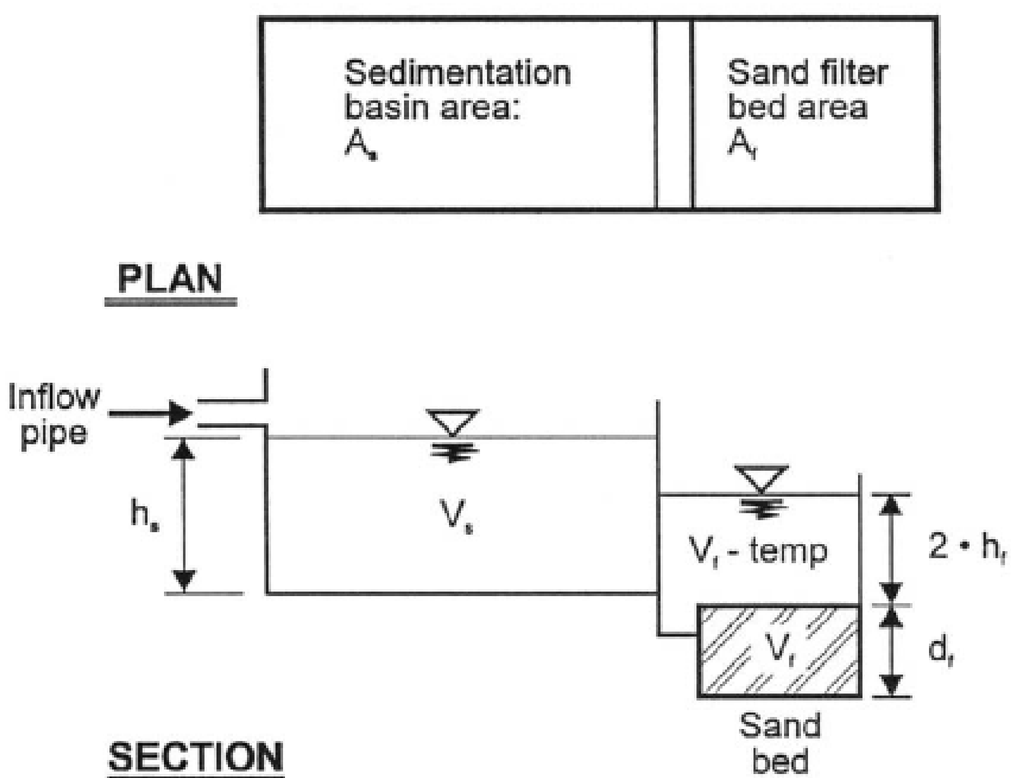
2F-2 Design of Surface and Perimeter Sand Filter

A. Physical specifications and geometry

1. **Surface sand filter.**

   a. The entire treatment system (including the sedimentation chamber) must temporarily hold at least 75% of the WQv prior to filtration. Figure 1 illustrates the distribution of the treatment volume (0.75 WQv) among the various components of the surface sand filter, including:
      1) V_s – volume within the sedimentation basin
      2) V_f – volume within the voids in the filter bed
      3) $V_{f\text{-temp}}$ – temporary volume stored above the filter bed
      4) A_s – the surface area of the sedimentation basin
      5) A_f – surface area of the filter media
      6) h_s – height of water in the sedimentation basin
      7) h_f – average height of water above the filter media
      8) d_f – depth of filter media

Figure 1: Surface sand filter volumes



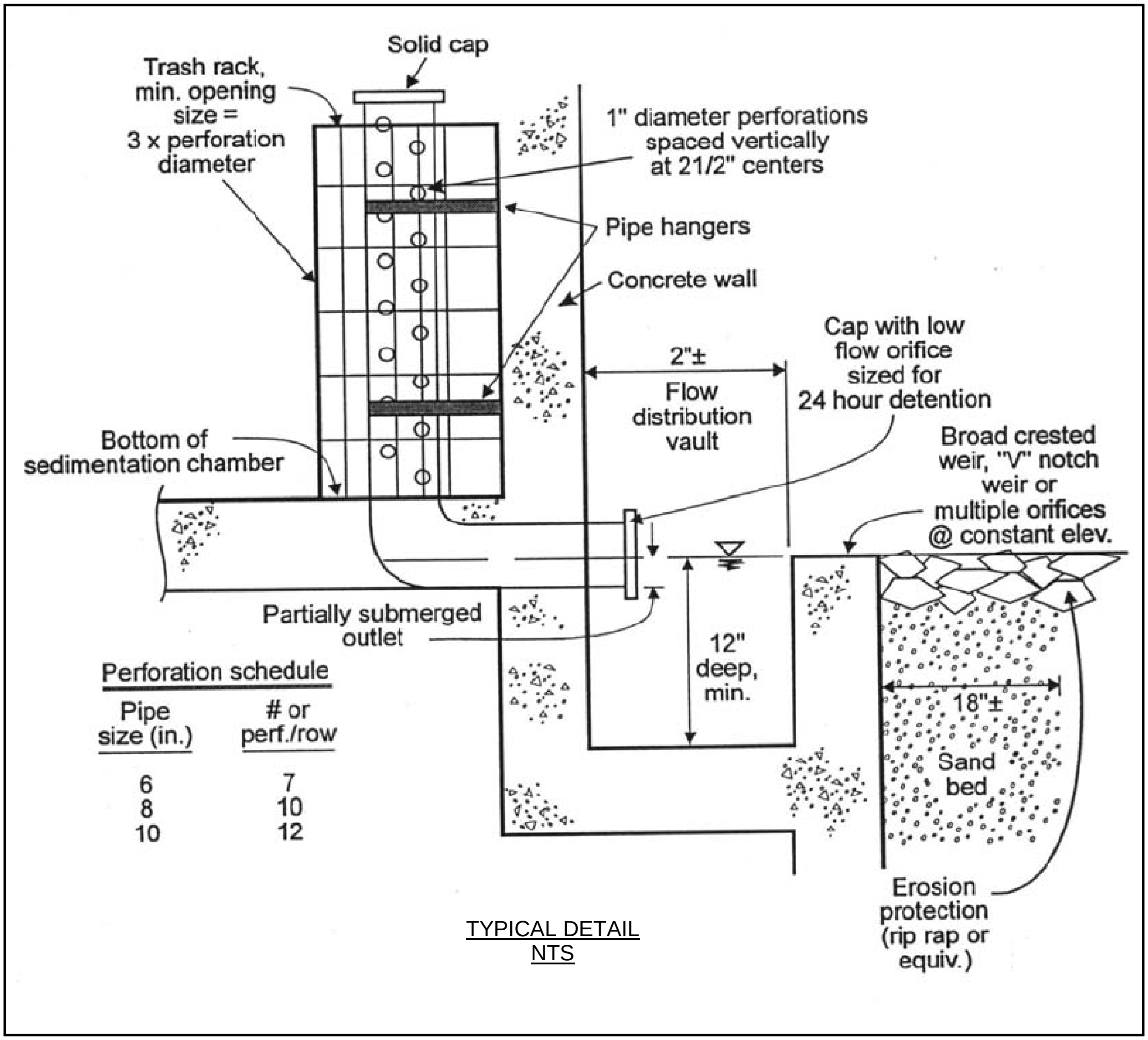
Source: Claytor and Schueler, 1996

   b. The basin bottom should be nearly level to facilitate sedimentation.

c. Figure 2 shows a typical inlet pipe from the sedimentation chamber to the filter media basin for a surface sand filter.

d. The filter area is sized based on the principles of Darcy's Law. A coefficient of permeability (k) of 3.5 ft/day for sand should be used. The filter bed is typically designed to completely drain in 40 hours or less.

Figure 2: Surface sand filter perforated inlet standpipe



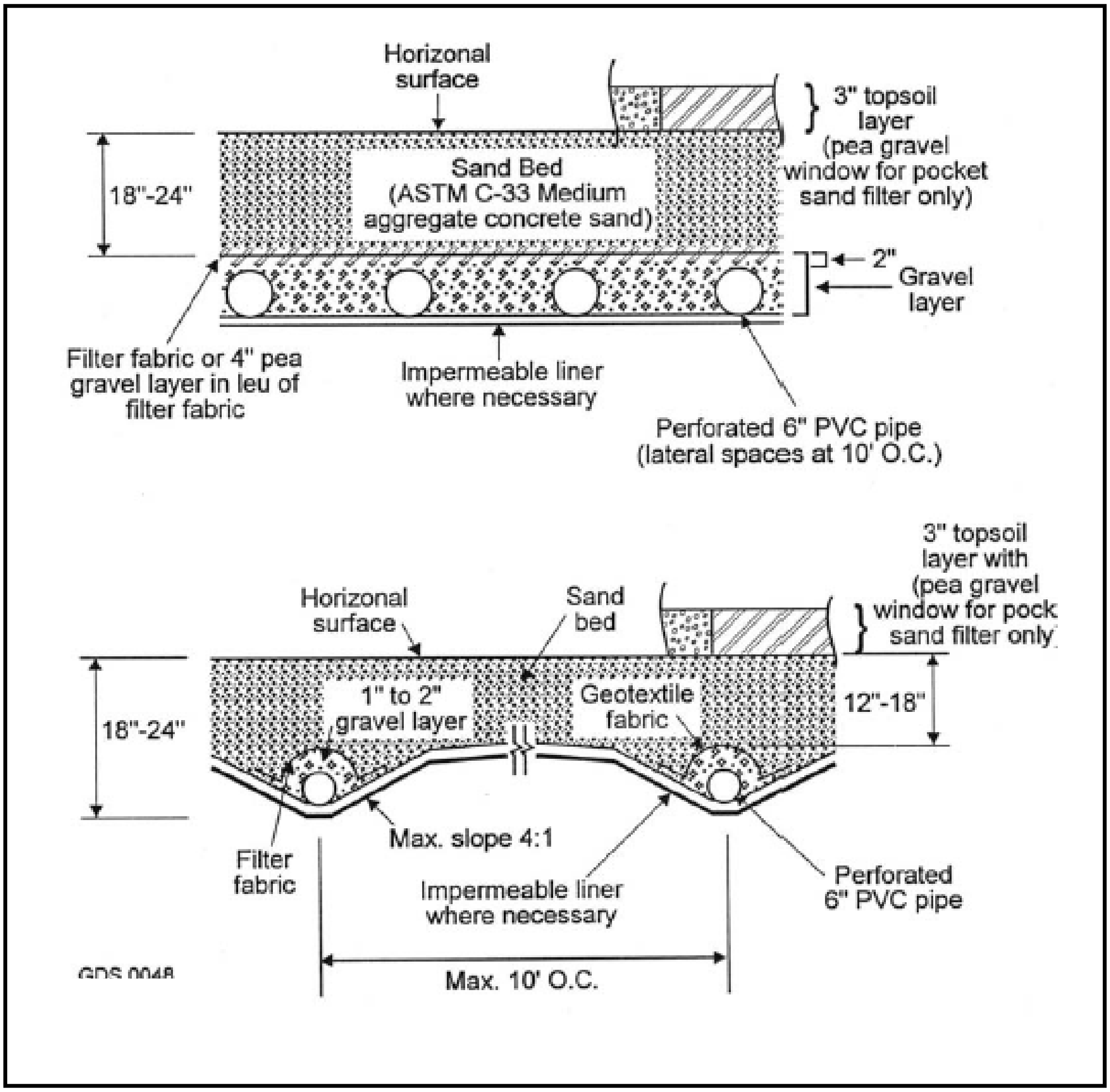
Source: Claytor and Schueler, 1996

e. The filter media consists of an 18-inch layer of clean washed medium sand (meeting ASTM C-33 concrete sand or Iowa DOT Fine Aggregate Size No. 10) on top of the underdrain system. A typical sand media gradation is shown in Table 1.
f. Three inches of topsoil are placed over the sand bed. Permeable filter fabric is placed both above and below the sand bed to prevent clogging of the sand filter and the underdrain system. Figure 3 illustrates a typical media cross section.

Table 1: Sand medium specification

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

Figure 3: Typical sand filter media cross sections



Source: Claytor and Schueler, 1996

g. The filter bed is equipped with a 6-inch perforated PVC pipe (AASHTO M252) underdrain in a gravel layer. The underdrain must have a minimum grade of 1/8 inch per foot (1% slope). Holes should be 3/8-inch diameter and spaced approximately 6 inches on center. Gravel should be clean washed aggregate with a maximum diameter of 3.5 inches, a minimum diameter of 1.5 inches, and a void space of about 40% (Iowa DOT No. 3 stone). Aggregate contaminated with soil shall not be used.

h. The structure of the surface sand filter may be constructed of impermeable media such as concrete, or through the use of excavations and earthen embankments. When constructed with earthen walls/embankments, filter fabric should be used to line the bottom and side slopes of the structures before installation of the underdrain system and filter media.

2. **Perimeter sand filter.**

a. The entire treatment system (including the sedimentation chamber) must temporarily hold at least 75% of the WQv prior to filtration. Figure 4 illustrates the distribution of the treatment volume (0.75 WQv) among the various components of the perimeter sand filter, including:
1) V_w – wet pool volume within the sedimentation basin
2) V_f – volume within the voids in the filter bed
3) $V_{f\text{-}temp}$ – temporary volume stored above the filter bed
4) A_s – the surface area of the sedimentation basin
5) A_f – surface area of the filter media
6) h_f – average height of water above the filter media (1/2 htemp)
7) d_f – depth of filter media

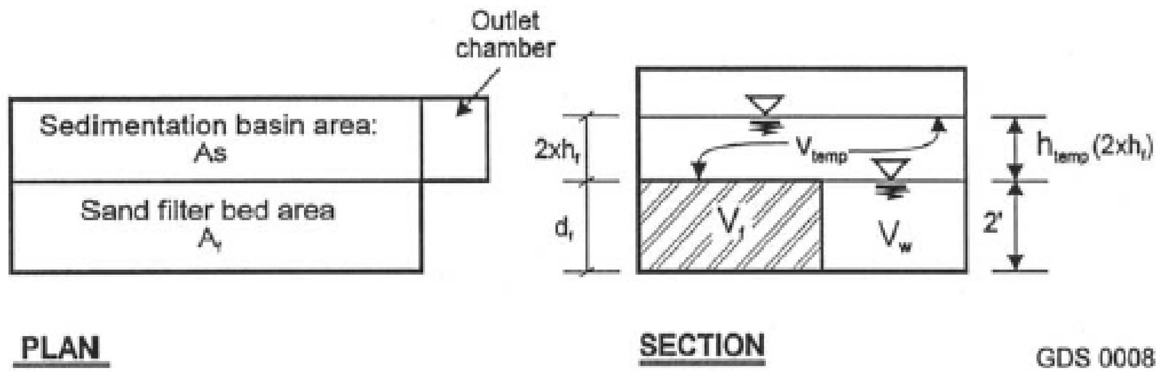
b. The sedimentation chamber is sized to at least 50% of the computed WQv.

c. The filter area is sized based on the principles of Darcy’s Law. A coefficient of permeability (k) of 3.5 feet per day for sand should be used. The filter bed is typically designed to completely drain in 40 hours or less.

d. The filter media consists of a 12- to 18-inch layer of clean washed medium sand (meeting ASTM C-33 concrete sand or Iowa DOT Fine Aggregate Size No. 10) on top of the underdrain system. Figure 3 illustrates a typical media cross section.

e. The perimeter sand filter is equipped with a 4-inch perforated PVC pipe (AASHTO M 252) underdrain in a gravel layer. The underdrain must have a minimum grade of 1/8 inch per foot (1% slope). Holes should be 3/8-inch diameter and spaced approximately 6 inches on center. A permeable filter fabric is placed between the gravel layer and the filter media. Gravel is a clean washed aggregate with a maximum diameter of 3.5 inches, a minimum diameter of 1.5 inches, and a void space of about 40% (Iowa DOT No. 3 stone). Aggregate contaminated with soil shall not be used.

Figure 4: Perimeter sand filter volumes



Source: Claytor and Schueler, 1996

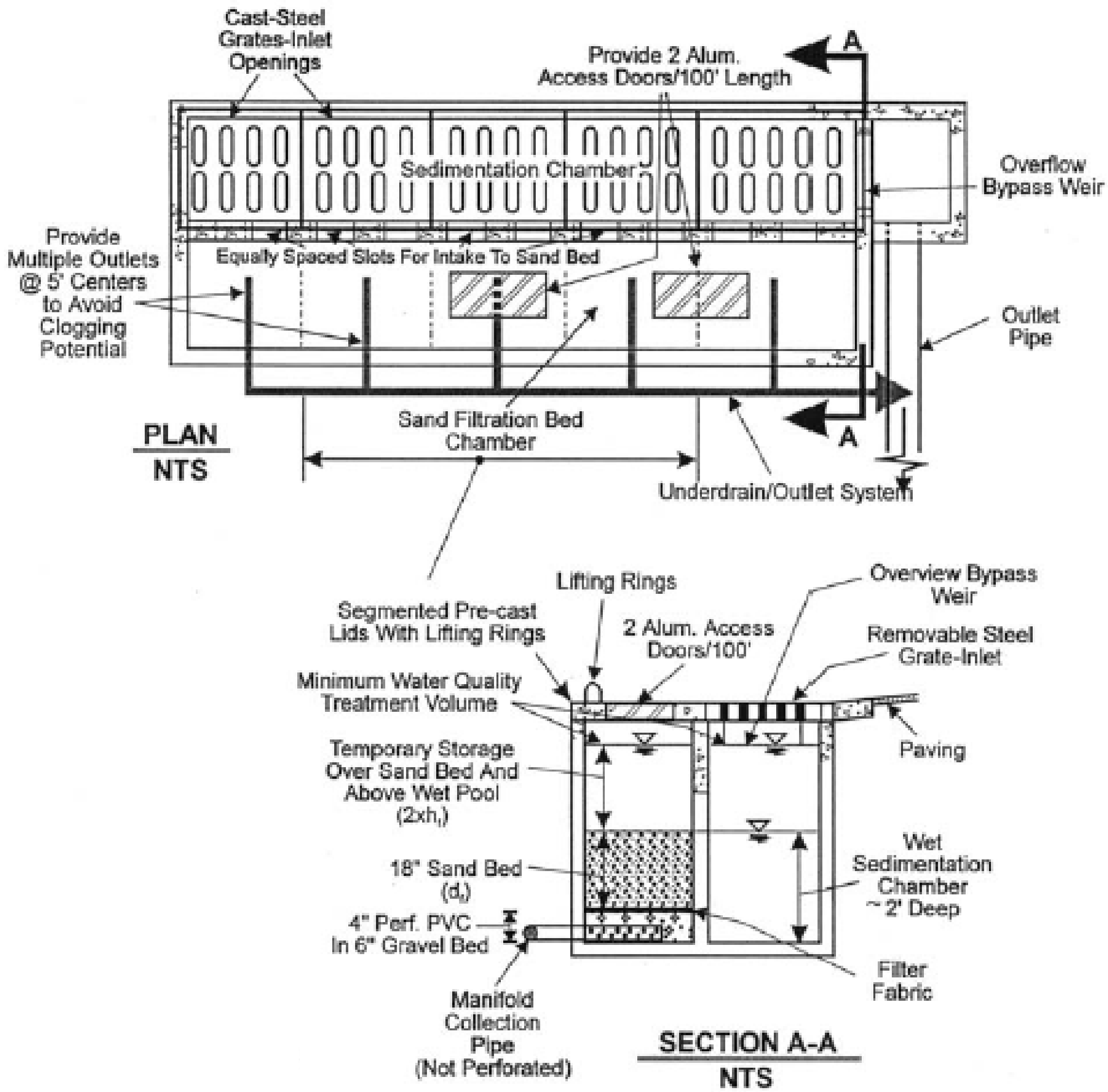
B. Pre-treatment/inlets

1. Pre-treatment of runoff in a sand filter system is provided by the sedimentation chamber.

2. Inlets to surface sand filters should be provided with energy dissipators. Exit velocities from the sedimentation chamber must be non-erosive.

3. Figures 2 and 5 show typical inlet configurations from the sedimentation basin to the filter media basin for the surface sand filter.

Figure 5: Perimeter sand filter



Source: Adapted from Claytor & Schueler, CWP, 1996

C. Outlet structures

Outlet pipe is to be provided from the underdrain system to the facility discharge. Due to the slow rate of filtration, outlet protection is generally unnecessary (except for auxiliary overflows and spillways).

D. Auxiliary spillway

An auxiliary or bypass spillway is included in the surface sand filter to safely pass flows that exceed the design storm flows. The spillway prevents filter water levels from overtopping the embankment and causing structural damage. The auxiliary spillway should be located so that downstream buildings and structures will not be impacted by spillway discharges.

E. Maintenance access

Adequate access must be provided for all sand filter systems for inspection and maintenance, including the appropriate equipment and vehicles. Access grates to the filter bed need to be included in a perimeter sand filter design. Facility designs must enable maintenance personnel to easily replace upper layers of the filter media.

F. Safety features

Surface sand filter facilities can be fenced to prevent access. Inlet and access grates to perimeter sand filters may be locked.

G. Landscaping

Surface sand filters can be designed with a vegetated cover to aid in pollutant removal and to reduce clogging. The vegetation should be capable of withstanding frequent periods of inundation and drought.

H. Additional site-specific design criteria and considerations

1. **Physiographic factors.** Local terrain design constraints:

    a. **Low relief.** Use of surface sand filter may be limited by low head.

    b. **High relief.** Filter bed surface must be level.

    c. **Karst.** Use poly-liner or impermeable membrane to seal bottom of earthen surface sand filter or use watertight structure.

2. **Soils.** No restrictions.

3. **Special downstream watershed considerations.**

    a. **Coldwater fishery stream.** Evaluate for stream warming; use shorter drain time (24 hours).

    b. **Aquifer protection.** Use poly-liner or impermeable membrane to seal bottom of earthen surface sand filter or use watertight structure; no exfiltration of filter runoff into groundwater.

I. Design procedures

1. **Step 1.** Compute runoff control volumes from the unified stormwater sizing criteria.

    a. Calculate the water quality volume (WQv), channel protection volume (Cpv), overbank flood protection volume (Qp), and the extreme flood volume (Qf).

    b. Details on the unified stormwater sizing criteria and hydrologic calculations are found in Parts 2B and 2C.

2. **Step 2.** Determine if the development site and conditions are appropriate for the use of a surface or perimeter sand filter. Consider the Application and Feasibility criteria in Section 2F-1.

3. **Step 3.** Confirm local design criteria and applicability.

   a. Consider any special site-specific design conditions/criteria. (See Section 2F-1).

   b. Check with local jurisdiction officials or other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

4. **Step 4.** Compute WQv peak discharge (Q_{WQ}). (See Section 2C-7). The peak rate of discharge for water quality design storm is needed for sizing of off-line diversion structures (see Section 2C-7).

   a. Using WQv, compute CN.

   b. Compute time of concentration using NRCS WinTR-55 method.

   c. Determine appropriate unit peak discharge from time of concentration.

   d. Compute Q_{WQ} from unit peak discharge, drainage area, and WQv.

5. **Step 5.** Size flow diversion structure, if needed.

   a. A flow regulator (or flow splitter diversion structure) should be supplied to divert the WQv to the sand filter facility.

   b. Size low flow orifice, weir, or other device to pass Qwq. (See Table 1).

6. **Step 6.** Size filtration basin chamber.

   a. The filter area is sized using the following equation (based on Darcy's Law):

   $$A_f = (WQv)\ (d_f)\ /\ [(k)\ (h_f + d_f)\ (t_f)]$$ **Equation 1**

   Where:
   A_f = surface area of filter bed (ft^2)
   d_f = filter bed depth (typically 18-in, no more than 24-in
   k = coefficient of permeability of filter media (ft/day); use 2-3.5 ft/day for sand
   h_f = average height of water above filter bed (ft); (½ h_{max} ; varies based on site; h_{max} is typically ≤ 6 ft
   t_f = design filter bed drain time (days); (1.67 days or 40 hrs is recommended maximum)

   b. The "k" values for sand were computed by the City of Austin staff based on field observation and actual performance of previously installed sand filters. The values ranged from approximately 0.5-2.7 ft/day, with an average value of 1.5 ft/day. These values are substantially lower than those quoted in textbooks (Hwang, 1981), but allow for clogging associated with accumulated sediments. With an appropriately-sized sedimentation basin (as described above), a value of k = 2-3.5 ft/day is recommended (City of Austin, TX, 1988). See Table 2 for "k" values for alternative media.

Table 2: Coefficient of permeability values for stormwater filter media

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

Source: Claytor and Schueler, CRC, 1996)

c. Set preliminary dimensions of filtration basin chamber.

d. See Section 2F-1 and SUDAS Specifications manual Section 9040 for filter media criteria.

7. **Step 7.** Size sedimentation chamber.

a. **Surface sand filter.**

1) The sedimentation chamber is sized to at least 25% of the computed WQv and has a length-to-width ratio of at least 2:1.
2) Inlet and outlet structures should be located at opposite ends of the chamber.
3) The Camp-Hazen equation is used to compute the required surface area:

$A_s = -(Qo/v_p) \times \ln(1-E)$ **Equation 2**

Where:
A_s = sedimentation surface area (ft^2)
Q_o = rate of outflow = capture volume release over a 24-h period
v_p = particle settling velocity (ft/sec)
E = trap efficiency

Assuming:
- 90% trap efficiency
- particle settling velocity (fps) = 0.0033 fps for imperviousness < 75%
- particle settling velocity (fps) = 0.0004 fps for imperviousness ≥ 75%
- average of 24-hour holding period

Then:
- $A_s = (0.066) \times (WQv)\ ft^2$ for $I < 75\%$ **Equation 3**
- $A_s = (0.0081) \times (WQv)\ ft^2$ for $I \geq 75\%$ **Equation 4**
- (I = imperviousness)

4) Removal of discrete particles by gravity settling is primarily a function of surface loading (the rate of outflow divided by the basin surface area) and is independent of basin depth. A minimum basin depth of 3 feet is recommended to minimize particle re-suspension and turbulence effects. Therefore, surface area is the primary design parameter for sedimentation affecting removal efficiency (E). E is also a function of particle size distribution. Silt-sized particles are used as the target particle size for sedimentation basin design (i.e., < 20 microns).

5) For sites with imperviousness > 75%, which have a higher percentage of coarse-grained sediments (Shaver and Baldwin, 1991), the target capture particle is approximately 40 microns.
6) Set preliminary dimensions of sedimentation chamber.

b. **Perimeter sand filter.** The sedimentation chamber should be sized to at least 50% of the computed WQv. Use same approach as for surface sand filter.

8. **Step 8.** Compute the minimum filter volume, $V_{min.}$

a. Typical design for filtration and infiltration practices is to capture and retain the WQv. However, for sand media filters, where pervious areas are intentionally limited, the runoff for the WQv can be a sizable quantity, and complete storage is often not feasible or is cost-prohibitive. Therefore, although the WQv is used to size minimum surface areas for both the sedimentation and filter bed chambers, a volume of three-quarters of the WQv is maintained as the minimum storage volume required.

b. Storing three-quarters of the WQv versus 100% of WQv is justified since the sedimentation chamber is continually draining into the filter bed during the course of a storm event. Only short duration, high intensity storms are likely to exceed the three quarters WQv threshold.

$V_{min} = 0.75 \times WQv$ **Equation 5**

9. **Step 9.** Compute storage volumes within the entire facility and determine sedimentation chamber orifice size.

a. **Surface sand filter**. The overall design is based on fitting the structure to the existing site and remaining within the sizing limits. Based on past experience, 75% of the WQv must fit within the three basic compartments in the sand filter: sedimentation chamber, head above the sand bed, and saturated pore spaces within the sand bed as indicated below:

$V_{min} = 0.75WQv = V_s + V_f + V_{f\text{-}temp}$ **Equation 6**

1) Compute V_f = water volume within filter bed/gravel /pipe = $A_f \times d_f \times n$ (n=porosity = 0.4 for most applications).
2) Compute $V_{f\text{-}temp}$ = temporary storage volume above the filter bed = $2 \times h_f \times A_f$
3) Compute V_s = volume within the sedimentation chamber = $V_{min} - V_f - V_{f\text{-}temp}$
4) Compute h_s= height in sedimentation chamber = V_s / A_s
5) Check that h_s and h_f match with the available head at the site and other dimensions fit – adjust as necessary in design iterations until all dimensions fit the available space.
6) Size orifice from sediment chamber to filter chamber to release V_s within 24 hours at average release rate with 0.5 h_s as average head.
7) Design outlet structure with perforations allowing for a safety factor of 10.
8) Size distribution chamber to spread flow over filtration media – level spreader weir or orifices.

b. **Perimeter sand filter.** Computation for the perimeter sand filter generally follows the procedure for the surface sand filter; the volume calculations change as noted below:
1) Compute V_f = water volume within filter bed/gravel /pipe = $A_f \times d_f \times n$ (n=porosity = 0.4 for most applications).
2) Compute V_w = wet pool storage volume = A_s x 2-ft minimum
3) Compute V_{temp} = temporary storage volume = $V_{min} - (V_f + V_w)$
4) Compute h_{temp} = temporary storage height = $V_{temp} / (A_f + A_s)$
5) Check $h_{temp} \geq 2 \times h_f$; otherwise, decrease h_f and re-compute; check dimensions against available head and area and change as required in design iterations until all site dimension fit.

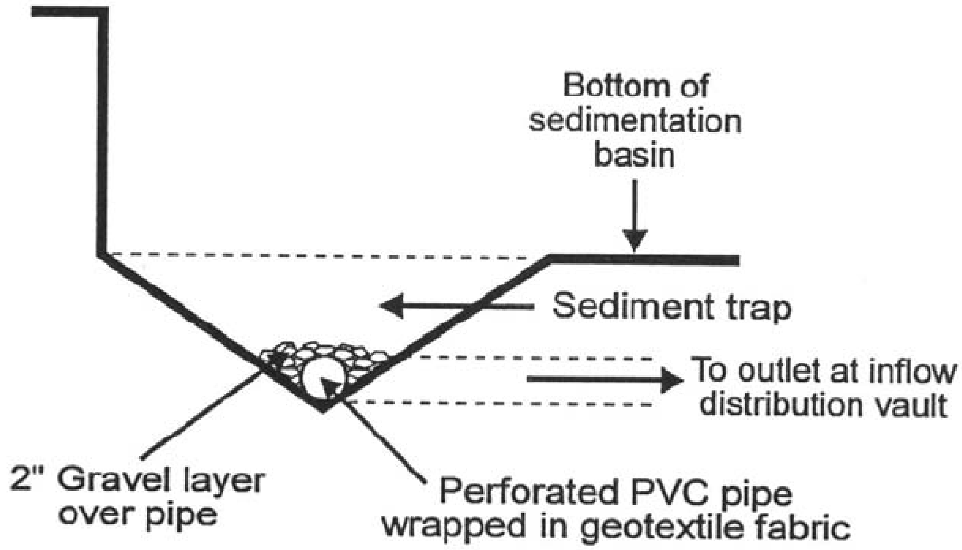
6) Size distribution slots from sediment chamber to filter chamber using the orifice equation.

10. **Step 10.** Design inlets, pre-treatment facilities, underdrain system, and outlet structures.

a. **Surface Sand Filter.**
1) Dry detention basin.
2) Minimum volume = 0.75 x WQv : split between volume within filter bed (voids), volume above filter bed, and volume within pre-treatment chamber.
3) Perforated standpipe with orifice sized to release volume (within sedimentation basin) over 24-hour duration (Figure 6. Note: The size and number of perforations depends on the release rate needed to achieve 24-hour detention.
4) Overflow weir within the sedimentation chamber is set at design treatment volume, sized to pass 2/3 of WQv peak flow. Overflow weir within sand bed chamber set at design treatment volume, sized to pass 1/3 of WQV peak flow. This ensures at least partial treatment for flows exceeding 0.75 x WQv.
5) Permanent sediment trap: Since the sedimentation basin is dry, a permanent sediment trap is recommended. This consists of a small storage area to trap incoming sediment and remove this from the basin flow regime. It is recommended that the sediment trap volume be equal to 10% of the sedimentation basin volume. Water collected in the trap is conveyed directly to the flow distribution vault (Figure 6.

b. **Perimeter sand filter.**
1) Wet retention basin.
2) Wet volume (V_w) = A_s x depth; (2' minimum depth permanent pool storage).
3) Total minimum volume = 0.75 x WQv: Split between volume within filter bed (voids), wet volume within sedimentation chamber, volume above wet volume, and volume above sand bed.
4) Elevation of overflow weir to outlet chamber set at top of dry storage elevation (0.75 x WQv), sized to pass 100% of incoming 10 year design flow.

Figure 6: Sediment trap configuration



Source: Adapted from Claytor and Schueler, CWP, 1996

11. **Step 11.** Compute overflow weir sizes.

    a. **Surface sand filter.**
       1) Size overflow weir at elevation hs in sedimentation chamber (above perforated stand pipe) to handle surcharge of flow through filter system from 25-year storm (see example).
       2) Plan inlet protection for overflow from sedimentation chamber and size overflow weir at elevation h_f in filtration chamber (above perforated stand pipe) to handle surcharge of flow through filter system from 25-year storm (see example).

    b. **Perimeter sand filter.** Size overflow weir at end of sedimentation chamber to handle excess inflow, set at WQv elevation.

J. Inspection and maintenance requirements

Table 3: Typical maintenance activities for sand filters

Maintenance Activity	Schedule
Ensure that contributing area, facility, inlets and outlets are clear of debris.	Monthly
Ensure that the contributing area is stabilized and mown, with clippings removed.	
Remove trash and debris.	
Ensure that the filter surface is not clogging (also check after significant storms).	
Minimize oil/grease/sediment entry to system.	
If permanent water level (perimeter sand filter), ensure against leaks.	
Ensure sediment chamber <50% full/sediment depth <6", or remove sediment.	Annually
Ensure drainage time <48 hours, or remove & replace top layers of filter media.	
Ensure no cracking or deterioration of concrete.	
Ensure no cracking or deterioration of concrete.	
Inspect grates (perimeter sand filter).	
Inspect grates (perimeter sand filter).	
Inspect inlets, outlets and overflow spillway to ensure good condition.	
Repair or replace any damaged structural parts.	
Stabilize any eroded areas.	
Ensure that flow is not bypassing the facility.	
Ensure no noticeable odors detected outside facility.	
Rake surface of filter bed.	As needed
Replace clogged filter fabric.	

Source: WMI, 1997; Pitt, 1997

1. A record should be kept of the dewatering time for a sand filter to determine if maintenance is necessary.

2. When the filtering capacity of the sand filter facility diminishes substantially (i.e., when water ponds on the surface of the filter bed for more than 48 hours), then the top layers of the filter media (topsoil and 2-3 inches of sand) will need to be removed and replaced. This will typically need to be done every 3-5 years for low sediment applications, more often for areas of high sediment yield or high oil and grease.

3. Removed sediment and media usually disposed of in a landfill.

4. Regular inspection and maintenance is critical to the operation of the sand filters. Responsibility for maintenance of the sand filter system must be assigned to a responsible authority through a legally binding and enforceable maintenance agreement. The maintenance agreement is executed as a condition of plan approval.

Table 4: Design procedures – sand filters

Preliminary Hydrologic Calculations						
1a	Compute WQv requirements					
	Design rainfall	P=		inches		
	Total drainage area for site	A_T=		acre		
	Impervious area	A_{impa}=		acre		
	% impervious area	Imp=		%		
	Compute runoff coefficient: Rv = 0.05+[0.009*(Imp%)]	Rv=				
	Compute WQv (WQv = [Rv*P*A]/12)	WQv=		acre-ft		ft^3
1b	Compute CPv	CPv=		acre-ft		
	Compute average release rate: 24-hr duration	Q_{avg}=		ft^3/s		
	Compute Qp-25	Qp-25=		ft^3/s		
Sand Filter Design						
2	Is the use of sand filter appropriate?	Low point in development area=				ft
		Low point at stream invert=				ft
		Total available head=				ft
		Average depth, h_f=				ft
3	Confirm local design criteria and applicability					
4	Compute WQv peak discharge (Q_{WQ}): WINTR-55	See Section 2C-7				
	Compute curve number (CN)	CN=				
	Compute time of concentration (Tc)	Tc=		hours		
	Compute Q_{WQ}	$Q_{WQ=}$		ft^3/s		
5	Size flow diversion structure	A=		ft^2		
	Low-flow orifice – orifice equation	diameter=		inches		
	Overflow weir – weir equation	length=		ft		
6	Size filtration bed chamber					
	Compute area from Darcy's Law	A_f=		ft^2		
	Using length-to-width ratio (2:1)	length=		ft		
7	Size sedimentation chamber					
	Compute area from Camp-Hazen equation	A_s=		ft^2		
	Using W from Step 5, compute length	length=		ft		
8	Compute V_{min}	V_{min}=		ft^3		
9	Compute filter component volumes					
	Surface Sand Filter					
	Volume within filter bed	V_f=		ft^3		
	Temporary storage above filter bed	V_{f-temp}=		ft^3		
	Sedimentation chamber (remaining volume)	V_s=		ft^3		
	Height in sedimentation chamber	h_s=		ft		
	Perforated standpipe – orifice equation	A=		ft^2		
	Perimeter Sand Filter					
	Compute volume in filter bed	V_f=		ft^3		
	Compute wet pool storage	V_w=		ft^3		
	Compute temporary storage	V_{temp}=		ft^3		
		h_{temp}=		ft		
10	Compute overflow weir sizes					
	Compute overflow – orifice equation	Q=		ft^3/s		
	Weir length from sedimentation basin – weir equation	length=		ft		
	Weir length from filtration chamber – weir equation	length=		ft		

K. Design example

Sand Filter.

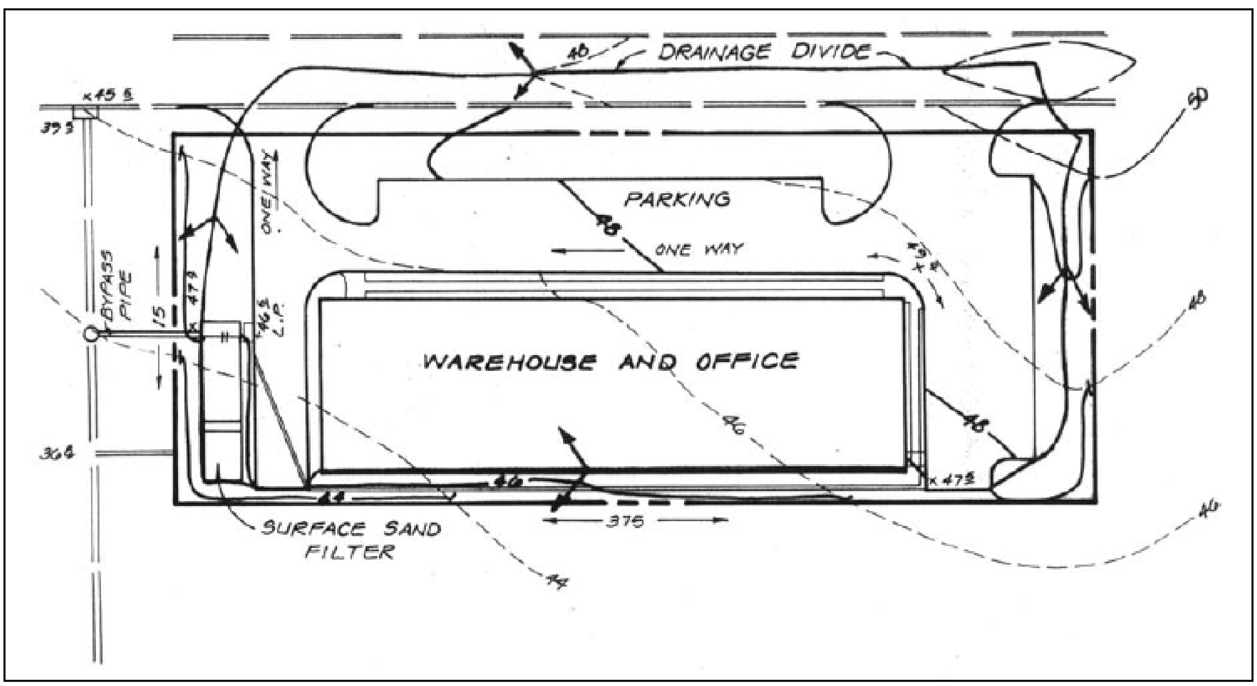
1. **Base site data.**

   a. Given: 2.2-acre site (see Figure 7)

   b. Light industrial-zoned (predominately building & parking)
      1) 0.90 acre paved
      2) 0.04 acre sidewalk
      3) 0.38 acre flat roof
      4) 0.02 acre filter practice
      5) 0.86 acre pervious

   c. % Impervious = (0.90 + 0.04 + 0.38 + 0.02) /2.2] x 100 = 61% *
      * Note: impervious area < 75%, use Equation 3 to size sedimentation chamber area (for I > 75% use Equation 4).

Figure 7: Bucketsville distribution center site plan



Source: Story County, Iowa

2. **Compute WQv.**

   a. P = 1.25 inches rainfall (from Parts 2B and 2C)

   b. From Tables 2 and 3 in Section 2B-1:
      1) Flat roofs: Rv = 0.86
      2) Large impervious area: Rv = 0.98
      3) Small imp. area (streets): Rv = 0.74
      4) Filter surface area: Rv = 1.00

5) Pervious areas (silty soils): Rv = 0.13

c. Weighted Rv = [(0.90)(.98) + (0.04)(.74) + (0.38)(.86) + (0.02)(1.0) + (0.86)(.13)] / 2.2

Rv = (0.88 + .03 + 0.33 + 0.02 + 0.11) / 2.2 = 0.63

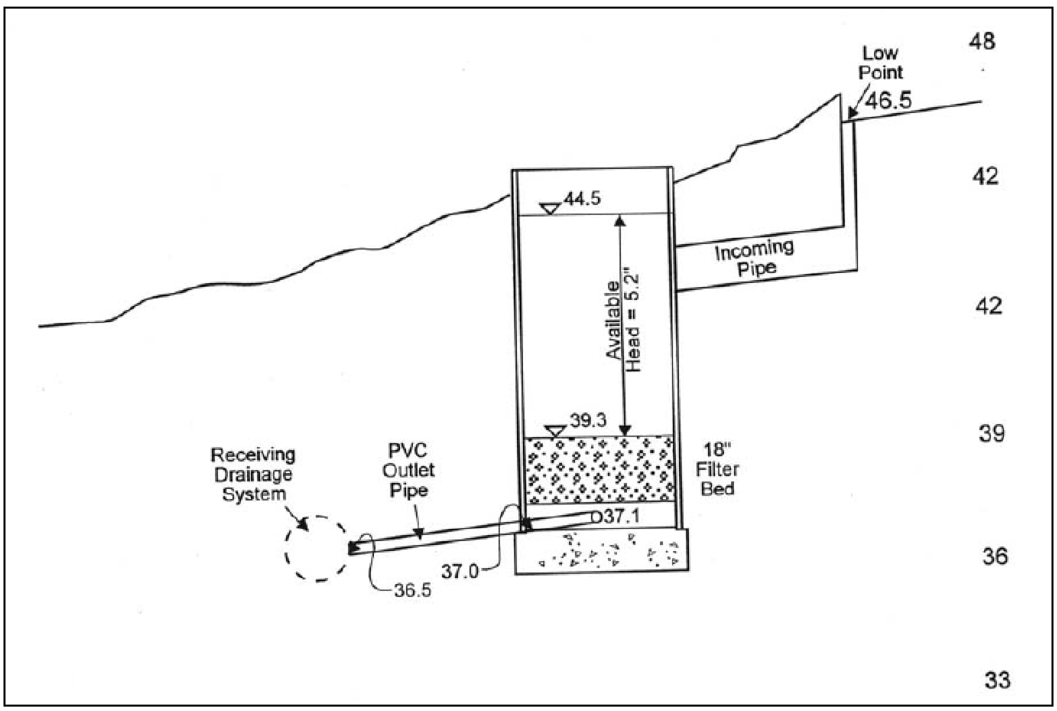
WQv = Rv x P = 0.63 x 1.25-in = 0.78 inches

WQv = 0.78-in x 2.2 ac x 1/12 = .14 acre-ft

WQv = .14 ac-ft x 43,560 ft^2/ac = 6,098 ft^3

d. Compute maximum head available (see site elevation sketch – Figure 8)
1) Low point in street = Elv 46.5 (subtract 2 feet to pass Q_{10} discharge) = Elev. 44.5
2) Invert @ storm drain system = Elev. 36.5
3) Invert out of filter bed = Elev. 37.0
4) Top of filter bed = Elev. 39.3
5) Allowable depth (2 x h_f) = 44.5 – 39.3 = 5.2 ft, use $2*h_f$ = 5 ft

Figure 8: Bucketsville distribution center site profile



3. **Compute WQv Peak Discharge (Q_{WQ}).** From Section 2C-7 and Modified NRCS WINTR55 procedure.

a. CN = $1000/[10+5P+10Q_a-10(Q_a^2 + 1.25Q_aP)^{0.5}]$
P = rainfall depth for water quality storm – 1.25 inches
Q_a = runoff volume, inches (equal to P x Rv)

b. CN = $1000 / [10 + 5(1.25") + 10(.78") – 10[(.78")^2 + 1.25(0.78")(1.25")]^{0.5}$

c. CN = 94.94 Use CN = 95

d. Use t_c = 0.1 hour

e. Compute Q_{WQ} using WINTR-55 using modified CN and t_c :
WINTR55 results for *modified* CN = 95 and tc = 0.1 hr:
For 1.25-inch rainfall, q_u = 768 csm/in
Q_{WQ} = 2.64 ft^3/sec

f. Compute 1-yr, 2-yr, and 10-yr peak discharge using conventional WINTR55 procedure:
1) For 61% impervious, B soils, CN=98 for Imp and CN=61 for open space
2) CN = 84
3) Use t_c = 0.1 hr
4) WINTR55 results:

Design Storm Event	Runoff Volume (inches)	Peak discharge, Q (cfs)	Unit discharge, q_u (csm/in)
1-yr	0.943	3.45	1002.51
2-yr	1.426	4.89	1422.78
10-yr	2.590	8.82	2563.12

4. **Size flow diversion structure (see Figure 9).**

a. Size low-flow pipe to pass Q_{WQ} of 2.64 ft^3/sec with 1.5 feet of head
1) $Q = C*A*(2gh)^{0.5}$
2) 2.64 ft^3/sec = 0.6 * A* [2(62.2 ft/sec^2)(1.5 ft]$^{0.5}$
3) A = 0.322 ft^2 = 0.785 d^2 (d = diameter)
4) d = 0.64 ft = 7.68 in   Use 8-inch diameter pipe

b. 10-year overflow elevation = 44.3 feet

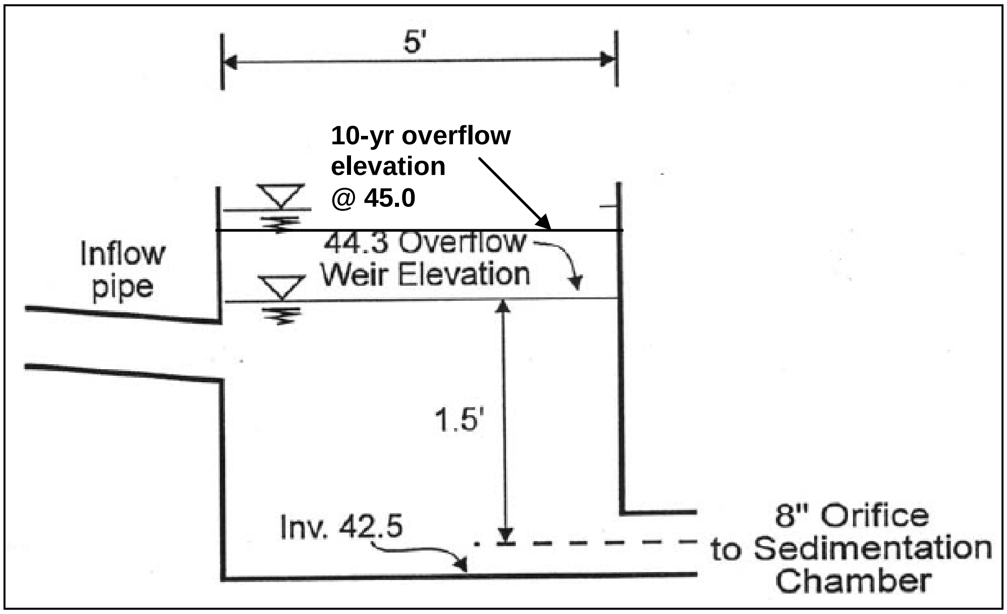
c. Set low-flow orifice invert elevation @ 44.3 – [1.5 + ((0.5 * 8")(1/12 ft/in))] = 42.47 ft

d. Set low-flow orifice invert elevation @ 42.5 feet

e. Compute overflow elevation in diversion structure (weir equation)
1) 10-year peak flow = 8.82 cfs
2) $Q = C*L*h^{3/2}$
3) 8.82 cfs = 3.1 * 5.0 ft * $h^{3/2}$
4) h = 0.69 ft
5) Overflow elevation = 44.3 + 0.69 = 45 ft

f. Size outlet pipe with 2 feet of head
1) $Q = C*A*(2gh)^{0.5}$
2) 8.82 cfs = 0.6 * A* [2(62.2 ft/sec^2)(2 ft]$^{0.5}$
3) A = 0.932 ft^2 = 0.785d^2
4) D = 1.09 ft = 13.08 inches   Use 15-inch RCP outlet pipe
5) Set invert @ Elev. 44.9 – [2 ft + ((0.5 * 15")(1/12 ft/in))] = 42.27 ft   Use 42.3 ft

Figure 9: Flow diversion structure



5. **Size sand filter bed.**

   a. $A_f = (WQv)\ (d_f) / [(k)\ (h_f + d_f)\ (t_f)]$ **Equation 7**

   b. Af = (6,098 ft3) (1.5-ft) / [(3.5 ft/d) (2.5-ft + 1.5-ft) (40-hr/24hr/d)]

   c. Af = 393 ft^2 = 16 ft x 24.5 ft Use 16 ft x 26 ft = 416 ft^2

   Where: d_f = 1.5 ft
   h_f = 2.5 ft
   k = 3.5 ft/day (See Table 2)
   t = 40 hours

6. **Size the sedimentation chamber.**

   Use Camp-Hazen Equation (for I < 75%) :

   A_s = (0.066/ft x (WQv) ft^2 **Equation 8**

   A_s = (0.066/ft) x (6,098 ft^3) = 402 ft^2

   For 16-foot width, 402 ft^2 / 16-ft = 25.12 ft Use 16 ft x 26 ft (416 ft^2)

7. **Compute V_{min} = 0.75 x WQv.** **Equation 9**

   V_{min} = 0.75 x (6.098 ft^3) = 4,574 ft^3

8. **Compute individual component volumes within the filtration structure.**

a. Compute volume within the filter bed (V_f): $V_f = A_f$ x d_f x *n*

V_f = 416 ft^2 x 2 ft x 0.4 = 332 ft^3

b. Compute temporary storage above the filter bed ($V_{f\text{-temp}}$): $V_{f\text{-temp}}$ = 2 x h_f x A_f

$V_{f\text{-temp}}$ = 2 x 2.5 ft x 416 ft^2 = 2080 ft^3

c. Compute remaining volume for sedimentation chamber (V_s): $V_s = V_{min} - V_f - V_{f\text{-temp}}$

V_s = 4,574 ft^3 – (332 ft^3 + 2080 ft^3) = 2,162 ft^3

d. Compute height in sedimentation chamber (h_s): $h_s = V_s / A_s$

h_s = 2,162 ft^3 / 402 ft^2 = 5.38 ft

5.38 ft > available head of 5.2 ft

Increase length of sedimentation chamber to 28 ft: As = 16 ft x 28 ft = 448 ft^2

h_s = 2,162 ft^3 / 448 ft^2 = 4.82 ft Use h_s = 5.0ft

h_s = 5.0 ft (hs > 2*h_f and h_s > 3 ft

5.0 ft is less than available head of 5.2 ft OK

9. **Compute overflow weir sizes.**

a. From sedimentation chamber (size to pass 2/3 of WQv peak discharge)

$Q_w = C*L*h^{3/2}$

0.67 x 2.64 cfs = 3.1 x L x $(1\text{ ft})^{3/2}$ L = 0.57 ft Use L = 0.6 ft

b. From filter bed chamber (size to pass 1/3 of WQv peak discharge)

$Q_w = C*L*h^{3/2}$

0.33 x 2.64 cfs = 3.1 x L x $(0.2\text{ ft})^{3/2}$ L = 3.14 ft Use L = 3.2 ft

Figure 10: Plan and profile of surface sand filter design example