

4. Design Guide

This section provides a step-by-step process for designing a VFS system. Engineers and other professionals should find this Design Guide template very useful in designing VFS systems using either integrated storage/settling basins or external storage/settling basins. The numbering of the steps in the Design Guide matches the step numbers used in the Case Studies found in Section 5 of the manual.

Step	Description	Method/Design Parameter	Equation	Variables	Value	Units
	Establish opportunity and constraint map for infiltration area					
Runoff Collection Area						
1.1	Establish extent of area contributing runoff	Identify on a map the drainage patterns around proposed collection area; define all areas contributing surface runoff to the collection area; eliminate all clean water sources (e.g., roof drains), diverting clean flow and other waste flow (e.g., milking centre washwater, etc.).				
1.2	Define and measure extent of runoff collection area	Measure the area contributing water to the runoff collection area.		A = runoff collection area		m ²
1.3	Select runoff coefficient (see Section 3.1.3)	Surface of runoff collection area must be impervious. A concrete surface with a runoff coefficient of 0.95 is assumed. Select runoff coefficient that describes the imperviousness of the existing surface of the runoff collection area.		C = runoff coefficient	0.95	N/A
1.4	Storage/settling volume and peak discharge rate					

Step	Description	Method/Design Parameter	Equation	Variables	Value	Units
1.4.1 (a)	Option 1 – Select design-storm event (see Section 3.1.4) for calculating the runoff storage/settling maximum basin volume requirements using the conservative method	Establish closest centre to farmstead from Table 6.1 and determine maximum storage/settling volume required.		Closest centre		
				V = storage settling volume		m ³
				A = runoff area		m ²
or						
1.4.1 (b)	Option 2 – Conservative maximum storage volume requirements based on a rainfall amount for a 25-year/24-hour storm event Use IDF Tables and Equation 3.1 to determine maximum storage volume	Calculate maximum storage volume.	$V_{max} = CaA$	$V_{max} =$ maximum storage volume		m ³
				C = runoff coefficient	0.95	
				a = rainfall amount 25-year/24-hour storm event		m
				A = runoff area		m ²
1.4.2 (a)	Option 1 – Minimum storage volume based on peak discharge rate of a 25-year storm return period for a 5-minute duration over a 15-minute period holding time	Establish closest centre to farmstead from Table 6.2. Establish peak discharge rate and minimum storage settling volume required from Table 6.2.		Closest centre		
				Peak discharge rate		m ³ /s
				Minimum storage settling volume required		m ³
or						
1.4.2 (b)	Option 2 – Use IDF Tables and Equation 3.2 and 3.3 to determine peak discharge rate and minimum storage/settling volume required	Calculate peak discharge rate from runoff collection area (Equation 3.2).	$q_p = .0027CiA$	$q_p =$ peak discharge rate		m ³ /s
				C = runoff coefficient	0.95	
				i = rainfall rate 25-year/5-minute storm event		mm/h
				A = runoff collection area		ha

Step	Description	Method/Design Parameter	Equation	Variables	Value	Units
	Calculate minimum storage/settling volume	Calculate minimum storage volume requirement with a minimum 15 minute (900 s) holding time (Equation 3.3).	$V_{min} = h_{tm} \times q_p$	$V_{min} =$ minimum storage/settling volume requirement		m^3
				$q_p =$ peak discharge		m^3/s
				$h_{tm} =$ minimum holding time	900	s
Storage Settling Basin						
2.1	Select storage type (see Section 3.2)	Determine preferred storage method: Integrated using containment wall or dedicated external basin.		Integrated Dedicated External		
2.2	Develop integrated storage/settling basin	Use if runoff collection area is suitable for development of a watertight basin and sufficient volume can be generated using a containment wall around all or portion of runoff containment area.				
2.2.1(a)	Determine maximum storage volume required	Volume is equal to the conservative maximum storage volume calculated in Step 1.4.1 (a) or Step 1.4.1 (b).		$V_{max} =$ maximum storage volume		m^3
or						
2.2.1(b)	Determine minimum storage volume required	Minimum storage volume is calculated in Step 1.4.2(a) or Step 1.4.2(b) .		$V_{min} =$ minimum storage volume		m^3
2.2.2	Establish containment wall height					
2.2.2.1	Establish containment wall height assembly with consistent slope	Calculate containment wall height using Equation 3.4.	$h = \sqrt{2Vs/L}$	$h =$ retaining wall height		m
				$V =$ volume of storage required		m^3

Step	Description	Method/Design Parameter	Equation	Variables	Value	Units
	perpendicular to runoff flow to low side			s = floor slope in the direction of flow		m/m
				L = runoff area length at right angles to flow		m
2.2.2.2	Establish containment wall height for runoff collection area that does not have one consistent slope to a low side	Methods available for calculating a volume based on a predicted elevation (top of wall) are the average end-area method, the planimeter method, and the average-depth method, or the creation of a 3-dimensional computer-generated terrain model.		h = retaining wall height		m
2.2.3	Establish total containment wall height	Establish final height required to accommodate runoff storage + 0.30 m for freeboard + 0.15 m for emergency overflow.	$h_t = h + 0.30 + 0.15$	h_t = total containment wall height		m
				h = retaining wall height		m
2.2.4	Calculate discharge rate from runoff collection area of integrated storage/settling basin with a holding time (h_{tm}) ranging from 4 to 10 hours (see Section 3.3.1)	Storage volume is equal to or greater than storage volume calculated in Step 2.2.1(a).	$q_{max} = V_{max}/h_{tm}$	q_{max} = discharge rate for maximum storage volume		m^3/s
				V_{max} = conservative maximum storage volume		m^3
				h_{tm} = holding time		s
		Storage volume is less than storage volume calculated in Step 2.2.1(a) but more than minimum storage volume from 25-year/5-minute storm event over a 15-	$q_o = q_p[1.25 - (1500V/RA + 0.06)^{0.5}]$	q_o = rate of outflow when pipe flows full		m^3/s
				q_p = peak flow = discharge from runoff collection area		m^3/s
				V = available storage volume		ha-m
		R = return period runoff		mm		

Step	Description	Method/Design Parameter	Equation	Variables	Value	Units
		minute period from Step 2.2.1(b).		25-year/24-hour		
				A = runoff collection area		ha
2.3	Develop dedicated external storage/settling basin					
2.3.1(a)	Determine maximum storage volume required	Maximum storage volume is equal to the storage volume calculated in Step 2.2.1(a).		V_{max} = maximum storage volume		m ³
or						
2.3.1(b)	Determine minimum storage volume required	Minimum storage volume is equal to storage volume calculated in Step 1.4.2(a) or Step 1.4.2(b).		V_{min} = minimum storage volume		m ³
2.3.2	Establish storage volume of existing facility					
2.3.2.1	Establish volume capacity of existing storage facility	Method used will depend on design of existing storage facility. Subtract freeboard height (0.3 m) and emergency overflow height (0.15 m) before calculating maximum storage volume.		V = storage volume		m ³
		If volume capacity is greater than minimum volume required, then existing storage facility may be used to accommodate runoff water.		If Yes, proceed to next step		
				If No, existing facility is not suitable for development of external dedicated basin		
2.3.2.2	Establish operating parameters for existing storage	Establish the following:				
		<ul style="list-style-type: none"> elevation of maximum 				m

Step	Description	Method/Design Parameter	Equation	Variables	Value	Units
	facility	storage volume				
		<ul style="list-style-type: none"> elevation of maximum storage volume minus freeboard (0.3 m) and emergency overflow height (0.15 m) 				m
		<ul style="list-style-type: none"> elevation of minimum storage volume 				m
2.3.3	Establish new dedicated external basin					
2.3.3.1	Establish basin dimensions	Select minimum basin depth of 1.45 m (1.0 m liquid depth plus 0.3 m freeboard plus 0.15 m spillway depth).		Minimum basin depth	1.45	m
		Establish the basin length to width ratio of 3 to 1 to accommodate required minimum storage volume.		Basin width		m
		Limit width of basin to between 3 m to 6 m to accommodate removal of solids using standard backhoe reach lengths.		Basin length		m
		Calculate basin depth for live storage from 2.3.1 (a) or 2.3.1 (b).		Basin depth for live storage		m
		Total basin depth is minimum basin depth plus basin		Total basin depth		m

Step	Description	Method/Design Parameter	Equation	Variables	Value	Units
		depth for live storage.				
2.3.4	Calculate discharge rate from external storage/settling basin	Storage volume available is equal to or greater than storage volume calculated in Step 2.3.1(a).	$q_{\max} = V_{\max}/h_{\text{tm}}$	q_{\max} = discharge rate for storage volume		m ³ /s
				V_{\max} = external storage volume		m ³
				h_{tm} = holding time		s
		Storage volume available is less than storage volume calculated in Step 2.3.1(a) but more than minimum storage volume from 25-year/5-minute storm event over a 15-minute period from Step 2.3.1(b).	$q_o = q_p [1.25 - (1500V/RA + 0.06)^{0.5}]$	q_o = rate of outflow when pipe flows full		m ³ /s
				q_p = peak inflow = peak discharge from runoff collection area		m ³ /s
				V = available storage volume		ha-m
				R = return period runoff 25-year/24-hour		mm
	A = runoff collection area		ha			
Runoff Collection/Discharge Bay						
3.1	Establish collection point where runoff exits collection area to external basin	Establish collection bay dimension (length and width) to accommodate screens and drainpipe area for integrated storage basin scenario. Minimum width of collection/discharge bay opening to be 1.0 m. Collection bay height equal to containment wall height. Only screening of coarse materials may be done.		Width of collection/discharge bay		m
				Length of collection/discharge bay		m
				Height of collection/discharge bay		m
3.2	Establish screen	Determine size		Screen width		m

Step	Description	Method/Design Parameter	Equation	Variables	Value	Units
	configuration (if applicable)	of screens based on the opening dimension of the collection/discharge bay. Install handle on top of screen to ease removal. Allow for c-channel width when establishing screen width.		Screen height		m
3.3	Select screen material (if applicable)	Select material for construction of coarse, medium and fine screen.		Material		
		1. Coarse – vertical spacing of approx. 25 mm (1 in.)		Material		
		2. Medium – vertical spacing of approx. 10 mm (3/8 in.)		Material		
		3. Fine – vertical spacing of approx. 3.1 mm (1/8 in.)		Material		
3.4	Calculate orifice plate opening based on orifice discharge capacity	1. Integrated Storage – select discharge rate from Step 2.2.4.	$A = Q/[(C)(2gh)^{0.5}]$	A = orifice opening area		m ²
				Q = discharge rate from integrated storage		m ³ /s
				C = orifice constant	0.61	
				g = acceleration due to gravity	9.8	m/s ²
				h = head on orifice		m
				$D = (4A/\pi)^{0.5}$		m
		2. External Storage – select discharge rate from Step 2.3.4.	$A = Q/[(C)(2gh)^{0.5}]$	A = orifice opening area		m ²
				Q = discharge rate from external storage		m ³ /s
				C = orifice constant	0.61	
				g = acceleration due to gravity	9.8	m/s ²

Step	Description	Method/Design Parameter	Equation	Variables	Value	Units
				h = head on orifice		m
			$D = (4A/\pi)^{0.5}$	D = orifice diameter		m
				A = orifice opening area		m ²
3.5	Calculate diameter of drainpipe	Select drainpipe to accommodate two times the discharge rate of the external storage/settling basin from Step 2.2.4 or 2.3.4.	$A = 2Q/[(C)(2gh)^{0.5}]$	A = area of drainpipe		m ²
				Q = discharge rate from external storage		m ³ /s
				C = orifice constant	0.61	
				g = acceleration due to gravity	9.8	m/s ²
				h = head on orifice		m
			$D = (4A/\pi)^{0.5}$	D = diameter of drainpipe		m
				A = area of drainpipe		m ²
3.6	Determine the minimum open area in the perforated riser pipe	Use Equation 3.7 to determine the size of the open slot or hole area in the perforated riser pipe. Increase the open area by 25%.	$A = 1.25Q/[(C) \times (2gh)^{0.5}]$	A = minimum slot or hole area		m ²
				Q = orifice discharge capacity		m ³ /s
				C = orifice constant	0.61	
				g = acceleration due to gravity	9.8	m/s ²
				h = head on orifice		m
		Choose individual slot size.		L = slot length		m
				W = slot width		m
		Calculate individual slot area.	Individual slot area = $L \times W$			m ²
		or				
		Choose individual hole diameter.		D = individual hole diameter		m
		Calculate individual hole area.	Individual hole area = $\pi D^2/4$			m ²
		Calculate number of slots or individual holes in perforated riser pipe.	No. of slots required = $A/\text{individual slot area}$			
			or			
			No. of holes required = $A/\text{individual hole area}$			

Step	Description	Method/Design Parameter	Equation	Variables	Value	Units	
3.7	Select sump	Select an appropriate size and type of sump. Maximum water depth in sump should be below frost line. Total sump depth equals frost-line depth plus depth to accommodate volume required by pump or siphon.		Sump volume (siphon/pump volume)		m ³	
				Establish sump volume and dimensions.	Sump length		m
					Sump width		m
					Sump depth		m
			Material of sump				
3.8	Select siphon device	Contact a siphon device manufacturer to select the most appropriate gravity flow mechanism in the sump.					
	Note: Contact sump, siphon/pump manufacturer for sump volume recommendations						
Conveyance Pipe							
4.1	Define target flow rate	Target conveyance pipe flow rate is 10% greater than storage/settling basin discharge rate from Step 2.2.4 or 2.3.4.		Orifice discharge rate from storage/settling basin increased by 10%		m ³ /s	
4.2	Establish minimum pipe/channel slope	Establish minimum pipe/channel slope based on Manning's Equation (Equation 3.9).	$A = Q/V$ $D = (4A/\pi)^{0.5}$ $R = D/4$ $S = (Vn/R^{2/3})^2$	A = area of pipe/channel		m ²	
				Q = flow rate		m ³ /s	
				V = velocity of flow	0.6	m/s	
				D = diameter of pipe		m	
			R = hydraulic		m		

Step	Description	Method/Design Parameter	Equation	Variables	Value	Units
				radius = area of water flow in pipe/channel divided by the wetted perimeter of pipe/channel; for circular pipe $R = D/4$		
				S = minimum slope of pipe/channel		m/m
				n = Manning's n, PVC Pipe (smooth inner walls)	0.009	
				Earth channel (grass covered)	0.03	
4.3	Establish design variables for evaluation of conveyance system	Establish the inlet elevation of the conveyance pipe/channel from the sump/drainpipe (gravity flow with adjacent infiltration area).		E_{INLET} = Inlet elevation of conveyance pipe (from sump) or conveyance channel (from drainpipe)		m
		Establish conveyance pipe/channel run length from sump/drainpipe to top of infiltration area.		L = length of conveyance pipe/channel run		m
		Establish the elevation of the existing grade at top end of the candidate infiltration area.		$E_{EXISTGRADE}$ = elevation at existing grade (at top end of infiltration area)		m
		Calculate outlet elevation of the conveyance pipe.		$E_{OUTLET} = E_{INLET} - (S)(L)$		
				E_{OUTLET} = outlet elevation of conveyance pipe		m
				S = minimum slope of conveyance pipe (see Step 4.2)		m/m

Step	Description	Method/Design Parameter	Equation	Variables	Value	Units
				L = length of conveyance pipe run		m
		Compare conveyance pipe outlet elevation with elevation of existing grade at top end of infiltration area. See Step 4.4.		E_{OUTLET} = outlet elevation of conveyance pipe		m
			$E_{EXISGRADE}$ = elevation at existing grade at top end of infiltration area (see Step 4.4)		m	
		Calculate elevation change between inlet elevation of conveyance pipe/channel from sump/ drainpipe and elevation of existing grade at top end of infiltration area.		$E_{CHANGE} = E_{inlet} - E_{exisgrade}$ E_{CHANGE} = elevation change (represents lift for pump system or drop for gravity system)		m
4.4	Determine gravity or pump system	If the existing grade at the top end of the infiltration area is lower than the conveyance pipe outlet elevation calculated, e.g., positive elevation change, then gravity flow to the top end of the infiltration area is possible. Rerun Manning's equation to ensure that slope between inlet elevation of conveyance pipe and existing grade at the top of the infiltration area generates a minimum pipe flow velocity of 0.6 m/s		Gravity flow		

Step	Description	Method/Design Parameter	Equation	Variables	Value	Units
		If the existing grade at the top of the infiltration area is higher than the conveyance pipe outlet elevation calculated, e.g., negative elevation change, then gravity flow to the top end of the infiltration area is not possible. A pump will be required to transfer the runoff to the top end of the infiltration area.		Pumped flow		
4.5	Determine target flow rate.	Target conveyance pipe flow rate is 10% greater than storage/settling basin discharge rate. See Step 4.1.		Orifice discharge rate from storage/settling basin		m ³ /s
				Target conveyance pipe flow rate (10% greater than orifice discharge rate from storage/settling basin)		m ³ /s
4.6	Determine total head losses between pump inlet and distribution pipe discharge	Determine head differential.		Difference in elevation between sump/drainpipe and existing grade at top end of infiltration area (see Step 4.3)		m
		To calculate pipe friction losses use Darcy-Weisbach Equation (Equation 3.8) with $f = 0.020$ or another equivalent method.	Friction losses = $f(L/D)(V^2/2g)$	Friction losses due to pipe run, including localized losses caused by pipe bends, valves, etc.		m
				$f =$ friction factor	0.020	
			$L =$ conveyance		m	

Step	Description	Method/Design Parameter	Equation	Variables	Value	Units
				pipe length		
				D = conveyance pipe diameter		m
				V = velocity of flow		m/s
				g = acceleration due to gravity	9.8	m/s ²
		Add pressure head of 0.9 m at the distribution pipe.		Distribution pipe pressure head	0.9	m
		Determine total head losses.	Total head losses = head differential plus pipe friction losses plus distribution pipe pressure head			m
4.7	Select type and size of pump	Select submersible sewage pump (preferably screw-induced flow) with automatic controls, capable of moving up to 24 mm solids. Obtain flow curves for selected pump and select the most efficient pump that will accommodate target conveyance pipe flow rate and head differential.		Manufacturer HP		
4.8	Determine pipe size required	The pipe size must be sufficient to convey the target discharge rate output. Check that pipe velocity does not exceed 1.5 m/s and friction losses are acceptable.		Conveyance pipe diameter		mm
4.9	Determine requirements	Calculate distance from		Check pump requirements		

Step	Description	Method/Design Parameter	Equation	Variables	Value	Units
	for power and controls	power source and effort required to power and automatically control pump.		(110 V or 220 V, or other)		
				Contact consultant or electrical contractor for recommendations		
Distribution Pipe						
5.1	Determine distribution pipe (or distribution channel) length	Determine actual distance pipe or distribution channel must distribute water from Step 6.7 (i.e., width of VFS).		Distribution channel to be gravel lined with geotextile fabric underneath		m
5.2	Select diameter (or width and depth) of distribution pipe or channel required	The distribution pipe (distribution channel) dimensions must be sufficient to convey the maximum siphon or pump output, or collection pipe orifice discharge capacity (gravity system) determined by flow and pipe velocity using Manning's Equation (Equation 3.9).	$D = 4[(Vn)/S^{0.5}]^{1.5}$	Distribution channel to be level on the downgradient side for even flow distribution along the length of the distribution channel		
				D = diameter of pipe		m
				V = velocity of flow		m/s
				n = Manning's n	0.009	
				S = slope of pipe		m/m
5.3	Determine capacity of orifice opening in distribution pipe	Use Equation 3.7; assume the head to be 0.90 m; assume C = 0.61.	$Q = (C)(A)(2gh)^{0.5}$	Q = orifice discharge capacity		m ³ /s
				C = orifice constant	0.61	
				A = orifice area		m ²
				g = acceleration due to gravity	9.8	m/s ²
				h = head on orifice		m
5.4	Determine number of orifices to meet flow capacity being delivered	Use a 1.25 target distribution rate. Divide the target discharge rate for the	No. of orifice = $1.25 \times \text{target discharge rate} / \text{orifice discharge rate}$	No. of orifices		

Step	Description	Method/Design Parameter	Equation	Variables	Value	Units
		distribution pipe by the orifice discharge rate determined in Step 5.3. Consider using a gated pipe with a minimum gate spacing of 0.6 m.	Orifice spacing = distribution pipe length/no. of orifices	Orifice spacing (centres)		m
Infiltration Area						
6.1	Determine minimum infiltration area required based on saturated hydraulic conductivity (Stage 1)	Determine the saturated hydraulic conductivity for the infiltration area soil.	Minimum infiltration area = target flow rate (Step 4.5) ÷ saturated hydraulic conductivity	On-site determination of saturated hydraulic conductivity required		m ²
6.2	Determine minimum infiltration area required based on liquid loading (Stage 2)	Use Table 3.3 to obtain highest normal monthly precipitation for closest station.		Maximum allowable liquid loading is 5 cm/week including rainfall		m/month
		Calculate highest normal weekly precipitation (highest normal monthly precipitation divided by 4).		Closest rainfall station is provided in Table 3.3		m/week
		Calculate outside paved yard weekly runoff volume.		Multiply the paved yard area by the highest normal weekly precipitation		m ³
		Calculate limiting precipitation amount per week on VFS.		The limiting precipitation amount per week is [5 cm minus highest normal weekly precipitation]		m
		Calculate minimum VFS area required.		The yard weekly runoff volume is divided by the limiting precipitation amount per week on VFS		m ²
6.3	Determine minimum	Select larger infiltration area				m ²

Step	Description	Method/Design Parameter	Equation	Variables	Value	Units
	infiltration area from Stage 1 (Step 6.1) and Stage 2 (Step 6.2)	from Step 6.1 and Step 6.2.				
6.4	Determine minimum length of infiltration area	Use Table 3.4 and VFS slope.				m
6.5	Determine minimum width of infiltration area	Use Equation 3.10.		Flow depth is 0.0127 m and flow velocity is found in Table 3.4		m
6.6	Calculate actual infiltration area dimensions	Select largest infiltration area from Stage 1 (Step 6.1) or Stage 2 (Step 6.2).		Minimum length of infiltration area comes from Step 6.4 (final width must be equal to or greater than distance calculated in Step 6.5)		m ²
6.7	Determine final dimensions of infiltration area	See Step 6.6 for final dimensions of infiltration area.		Final infiltration area dimensions	L = W = A =	m m m ²