CHAPTER 8 INFILTRATION FACILITIES

8.1 INTRODUCTION

This Chapter presents system, function and design of infiltration facilities. They serve primarily for removing the associated pollutants contained in the captured stormwater volume by filtration process through soil media above the groundwater table (GWT). The system can offer reduced pollutant loadings to downstream major runoff treatment BMPs, such as water quality ponds or wetlands. The main types of infiltration BMPs are sump, porous pavement, trench (Figure 8.1) and basin (Figure 8.2). The facilities are dry or empty when not in operation and are part of green park environment. The infiltration basin can provide additional functions of stormwater quantity controls and design of which shall be based on detention pond.

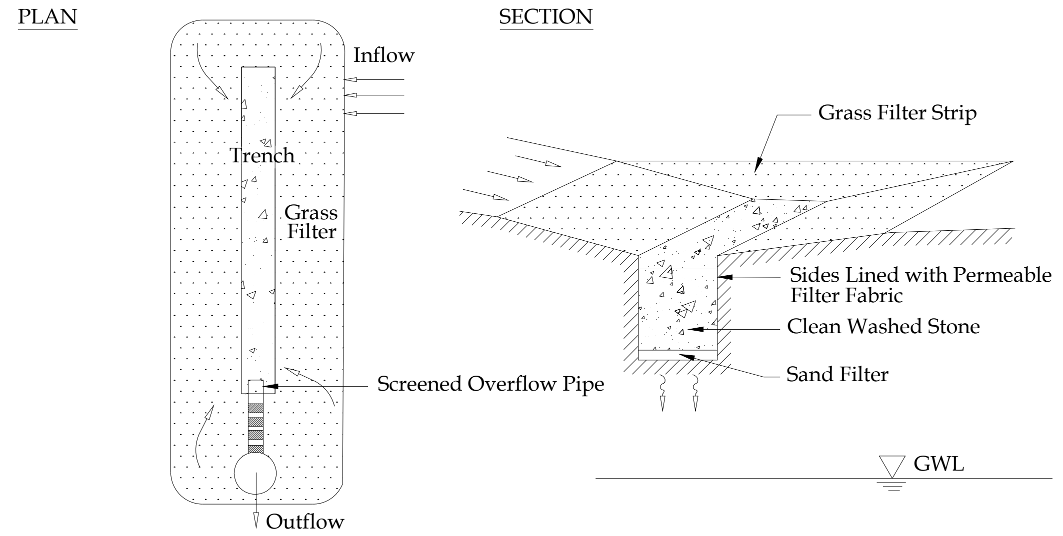


Figure 8.1: Typical Infiltration Trench Design

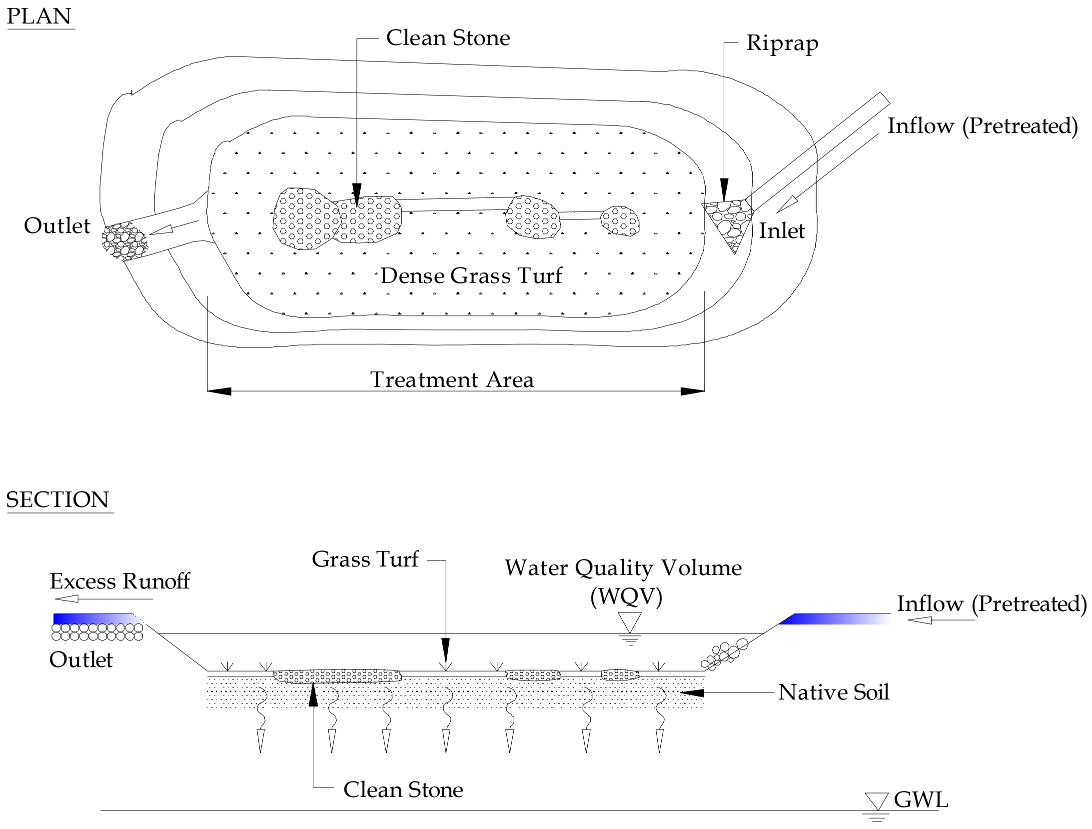


Figure 8.2: Typical Infiltration Basin Design

The facilities can be located on-site or along public drainage, depending on runoff contributing areas, pollution intensity and landuse practices being dealt with (Figure 8.3).

a) Infiltration Trench – Parking lot

b) Infiltration Basin - Residential

Figure 8.3: Typical Infiltration Application

8.2 PLANNING AND FEASIBILITY ANALYSIS

The infiltration facilities must be carefully selected, located, designed, and maintained to achieve their design benefits as well as to protect areas where groundwater quality is of concern. Infiltration can be successfully utilised if adherence to proper construction and maintenance standards is followed in accordance with its design life.

8.2.1 Drainage Area

Infiltration BMPs are limited in their ability to accept and treat flows from larger drainage areas. The types of infiltration BMPs and their drainage area limitations are given in Table 8.1.

Table 8.1: Infiltration BMPs and Drainage Area Limit

Infiltration BMPs	Maximum Drainage Area
Dispersion trenches/Infiltration sumps	500 m^2
Infiltration trenches/Porous pavements	4 hectares
Infiltration basins	15 hectares

8.2.2 Pollutant Removal Capabilities

Pollutant removal mechanisms in an infiltration system include absorption, filtration and microbial decomposition. Pre-treatment BMPs are required to remove coarse particulate matter and to reduce/prevent excessive pollutant loads entering the facilities. The typical removal capacity of infiltration facilities are summarised in Table 8.2.

Table 8.2: Typical Pollutant Removal Efficiencies for Infiltration BMPs (Fletcher et al., 2003)

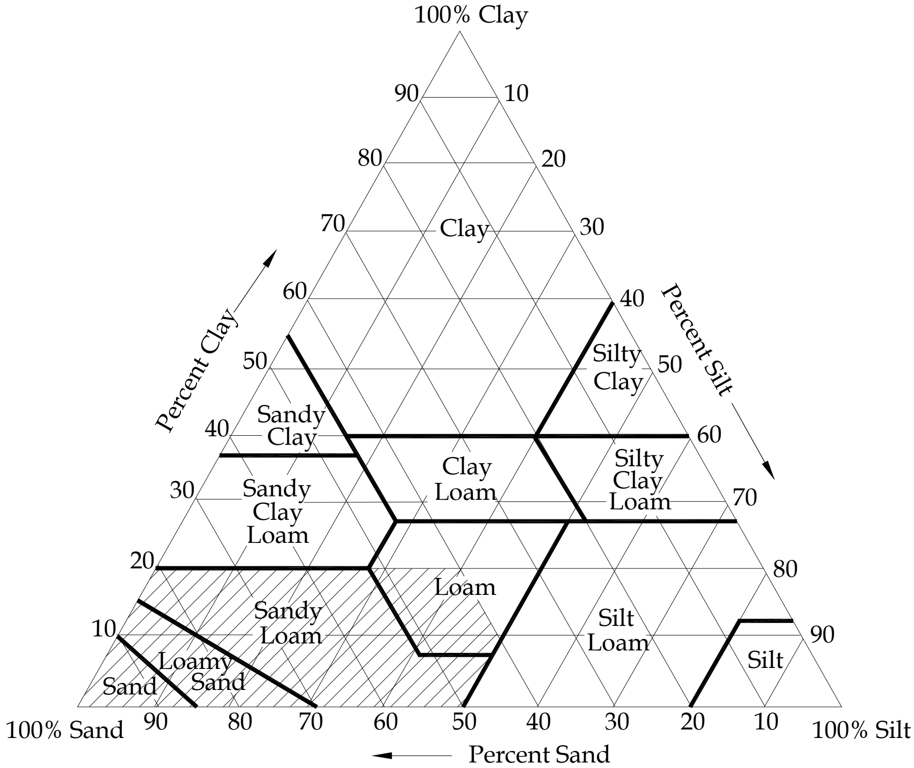
Pollutant	Expected Removal	Comments
Litter	>90%	Expected to trap all gross pollutants, except during high-flow bypasses
Total Suspended Solids	65 – 99%	Pre-treatment is required to reduce clogging risk
Total Nitrogen	50 – 70%	Depend on nitrogen speciation and state (soluble or particulate)
Total Phosphorus	40- 80%	Depend on nitrogen speciation and state (soluble or particulate)
Heavy Metals	50 – 95%	Depends on state (soluble or particulate)

8.2.3 Site Suitability Limitations

Soil types, surface geological conditions and groundwater levels determine the suitability of infiltration systems. For a site to be suitable, it must meet or exceed all of the criteria listed in Table 8.3. Should a site investigation reveal that any one of the Suitability Limitations cannot be met; the implementation of the infiltration practice should not be pursued.

Table 8.3: Site Suitability Limitations (DID, 2000).

Limitation	Comments
Soil	The suitability of soil for infiltration is to be based on evaluating the following: • Saturated soil infiltration rate should be a minimum rate of 13mm/hr • Soils with 30% or greater clay content or 40% greater silt/clay content should not be used (refer to the USDA Textural Triangle in Figure 8.4) • Aerobic conditions are to be maintained to the fullest extent possible for runoff treatment BMPs by designing them to drain the water quality design storm in 48 hours or less. • Infiltration systems should not utilise fill material or be placed over fill soils. (At locations where soils are unsuitable for infiltration or where water tables are high, it may be practical to provide infiltration through soil layers in fill, possibly collecting percolating water in pipes. This should not be ruled out, but suitable safeguards should be applied.)
Depth to Water Table, or Impermeable Layer (Bedrock)	The base of all facilities should be located at least 1.5m above the seasonal high ground water level and/or any impermeable layer (such as bedrock, clay lens, etc.).
Proximity to Drinking Water Wells, Building Foundations, Structures and Property Lines	The proximity of infiltration facilities to other structures and facilities must be taken into account where the potential exists to contaminate ground water, damage foundations and other property. The site investigation is required to determine the most appropriate locations of infiltration facilities; this is best done on a case-by-case basis but the following basic criteria are provided: • The facilities should not be allowed in well-field areas or near wells or springs used for drinking water supply. • Infiltration facilities should be situated at least 7m down-slope and 50m up-slope from building foundations. Infiltration sumps or trenches (on-site facilities) should be located at a minimum of 3m from any structure and 10m from a non-potable water supply well, septic tank or drain field. • Infiltration facilities on commercial and industrial sites, even though are not recommended, should be placed no closer than 35m from a non-potable water supply well, septic tank or drain field,
Land Slope	Infiltration facilities can be located on slopes up to 15% as long as the slope of the base of the facility is less than 3%. All basins should be a minimum of 20m from any slope greater than 15%.
Control of Siltation	During construction, it is critical not to excavate infiltration trenches or basins to final grade during this phase. After construction, it is vital to prevent as much sediment as possible from entering by first routing the water through a pre-treatment BMP. In the case of infiltration trenches, clogging occurs most frequently on the surface. Grass clippings, leaves and accumulated sediment should be removed routinely from the surface. If clogging appears to not be only at the surface, it may be necessary to remove and replace the first layer of filter media and the geotextile filter. In the case of infiltration basins, sediment should be removed when it is sufficiently dry so that the sedimentation layer can be readily separated from the basin floor



USDA Textural Triangle

Shaded area is applicable for design of infiltration BMPs

Figure 8.4: USDA Textural Triangle (USDA, 1971)

8.2.4 Design Criteria

8.2.4.1 Principles

The general principle in designing infiltration facilities is to capture the entire runoff water quality volume (WQV) of 40mm over the equivalent impervious contributing catchment area for water quality treatment purposes, whereas for water quantity regulation, the design acceptance criterion requires that the peak be reduced to the pre-developed value for the minor system design storm ARIs. Thus, the acceptance criteria for the design infiltration facilities require satisfying both standards.

8.2.4.2 Check List

The design criteria listed and discussed in this section are intended for designing infiltration facilities.

(i) Soil Investigation

Soil investigation is required for any type of infiltration facilities for each proposed development location in order to determine the soil type and groundwater level. Each soils log should extend a minimum of 3.0m below the bottom of the facility, describe the series of the soil, the textural class of the soil horizon(s) through the depth of the log and note any evidence of high ground water level. In addition, the location of impermeable soil layers or dissimilar soil layers should be determined.

(ii) Design Infiltration Rate

The design infiltration rate (f_d) should be one-half the infiltration rate (f_c) found from the soil textural analysis ($f_d = 0.5 f_c$).

(iii) Runoff Pre-Treatment

Suspended solids and pollutants in runoff should be pre-treated prior to discharge to any infiltration facilities.

(iv) Fill Material

Aggregate materials (for trenches and upper layers of infiltration basins) should consist of a clean aggregate with void space (i.e., porosity) in the range of 30 to 40%. The aggregate should be poorly graded.

(v) Buildings

Dispersion trenches, infiltration sump, infiltration trenches or porous pavement should be located 3m from building foundations. Meanwhile, infiltration basins should be a minimum of 50m upslope and 7m downslope from any building. Further, these facilities should be a minimum of 20m from any slopes greater than 15%. A geotechnical report should address the potential impact of the basin infiltration upon the steep slope.

(vii) Overflow Route

An overflow route must be identified in the event that the facilities capacity is exceeded (greater than minor system design ARI). The overflows must be connected to a conveyance system.

(vii) Spillways

The spillway requirement is only applied for the infiltration basin. All aspects of the principal spillway design and the emergency spillway should follow the details provided for detention pond in Chapter 7.

8.3 DESIGN PROCEDURE

8.3.1 General

The design methodologies presented here concentrate on two types of infiltration facilities: infiltration trenches and infiltration basins. The design methodology of all infiltration facilities should be applied to all type of facilities that emphasise on their contributing drainage areas. There are two general types of situations where infiltration facilities may be used.

- One may be interested in the dimensions of an infiltration device that is required to provide storage of the water quality volume (*WQV*), and/or downstream protection volume of runoff.
- The site conditions may dictate the layout and capacity of infiltration measures and one might be interested in determining the level of control provided by such a layout. In this, control may not be sufficient to meet stormwater treatment requirements, and additional control, possibly using other acceptable control measures (such as conveyance systems) may be required.

8.3.2 Design of On-site Facilities

8.3.2.1 General Considerations

The design procedure outlined in this section should be used in designing on-site trench systems that include dispersion trenches, infiltration sumps and infiltration trenches that their drainage contribution area is less than 500m^2.

The design of a trench system is based on the textural class of the soils underlying. The design of a trench system is also based on the maximum allowable depth of the trench (d_{max}) which should meet the following criteria:

$$d_{max} = \frac{f_c T_s}{n} \tag{8.1}$$

where,

f_c = Final infiltration rate of the trench area (mm/hr);
T_s = Maximum allowable storage time (hr); and
n = Porosity of the stone reservoir.

Design criteria for on-site facilities are provided in Table 8.4. A trench system is sized to accept the design volume that enters the trench (V_w) plus the volume of rain that falls on the surface of the trench (PA_t) minus the exfiltration volume ($f_d TA_t$) out of the bottom of the trench (Figure 8.5). Based on the analysis, the effective filling time for most trenches (T) will generally be less than two hours. The volume of water that must be stored in the trench (V) is defined as:

$$V = V_w + PA_t - f_d TA_t \qquad (8.2)$$

where,

P = Design rainfall event (mm);
A_t = Trench surface area (m^2);
V_w = Design runoff volume that enters the trench (m^3);
T = Effective filling time (hr), generally < 2; and
f_d = Design infiltration rate (mm/hr).

Table 8.4 Design Criteria of On-Site Infiltration Facilities

Design Parameters	Dispersion Trench/ Infiltration Sump	Infiltration Trench
Contributing drainage area	Up to 500m^2	Up to 500m^2
Soil investigation requirement	1 soil log test per site extending to 1.5m below of the trench bottom	1 soil log test every 15m of trench extending to 1.5m below of the trench bottom
Design infiltration rate (f_d)	f_d is equal to 0.5f_c with minimum f_c of 13mm/hr	f_d is equal to 0.5f_c with minimum f_c of 13mm/h
Maximum drawdown time	24hrs - Design ARI for Minor System	24hrs - Design ARI for Minor System
Design Runoff	Design ARI for Minor System (Quantity) Capture 40mm of rainfall over the contributing catchment area (Quality)	Design ARI for Minor System (Quantity) Capture 40mm of rainfall over the contributing catchment area (Quality)
Fill material	void space in the range of 30 to 40%	void space in the range of 30 to 40%
Maximum depth	1.5m above the seasonal groundwater or impermeable layer	1.5m above the seasonal groundwater or impermeable layer
Minimum clearance to special facilities	3m from building foundation 10m from non-potable water supply well	3m from building foundation 10m from non-potable water supply well
Overflow route	needs to be identified	needs to be identified
Observation well	1 every site (recommended)	1 every 15m of trench length

For most design storm events, the volume of water due to rainfall on the surface area of the trench (PA_t) is small when compared to the design volume (V_w) of the trench and may be ignored with little loss in accuracy to the final design.

The volume of rainfall and runoff entering the trench can be defined in terms of trench geometry. The gross volume of the trench (V_t) is equal to the ratio of the volume of water that must be stored (V) to the porosity (n) of the stone reservoir in the trench; V_t is also equal to the product of the depth (d_t) and the surface area (A_t):

$$V_t = \frac{V}{n} = d_t A_t n \tag{8.3}$$

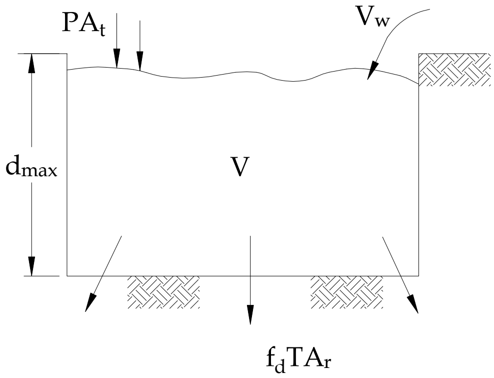


Figure 8.5: Model of Trench Hydrologic Balance

Combining Equations 8.2 and 8.3 yields the relationship: $d_t A_t n + f_d T A_t = V_w$. Because both dimensions of the trench are unknown, this equation may be rearranged to determine the area of the trench (A_t) if the value of d_t were set based on either the location of the water table or the maximum allowable depth of the trench (d_{max}):

$$A_t = \frac{V_w}{n d_t + f_d T} \tag{8.4}$$

In the event that the side walls of the trench must be sloped for stability during construction, the surface dimensions of the trench should be based on the following equation:

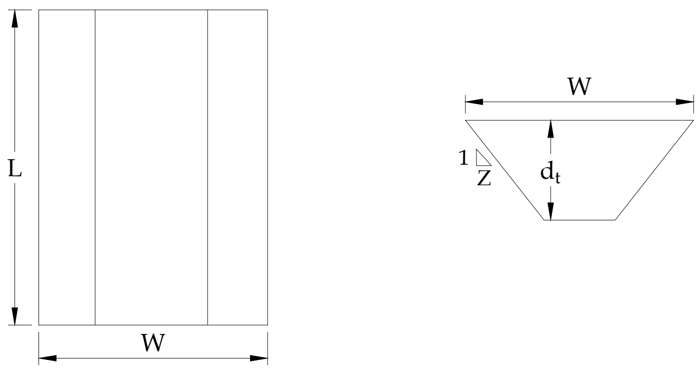
$$A_t = (L - Z d_t)(W - Z d_t) \tag{8.5}$$

where,

L = The top length (m);
W = The top width (m); and
Z = The trench side slope ratio.

The design procedure would begin by selecting a top width (W) that is greater than 2 x Zd_t for a specified slope (Z). The side slope ratio value will depend on the soil type and the depth of the trench. The top length (L) is then determined as:

$$L = Z d_t + \frac{A}{W - Z d_t} \tag{8.6}$$



a) Plan b) Side

Figure 8.6: Schematic of Trench

8.3.2.2 Design steps

This involves the following steps:

- Determine the contributed water quality volume (40 mm over the equivalent impervious contributing catchment area) from the development for storage to meet the runoff control requirement (acceptance criteria).
- Compute the maximum allowable depth (d_{max}) from the feasibility equation, $d_{max} = f_c T_s / n$.
- Compute volume of water that must be stored in the trench (V) as $V = V_w + PA_t - f_d TA_t$.
- Determine the surface area (A_t) dimensions of the trench as $A_t = (L - Zd_t)(W - Zd_t)$. This area should be
greater or equal than the area considered in the preliminary sizing.

8.3.3 Design of Community Facilities

8.3.3.1 General Considerations

The same principles as those applied in the previous section can be used as general design consideration for infiltration trench and basin, serving for larger catchment areas. The design of an infiltration basin facility is based on same soil textural properties and maximum allowable depths as an infiltration trench. However, because the infiltration basin uses an open area or shallow depression for storage, the maximum allowable depth (d_{max}) should meet the following criteria:

$$d_{max} = f_c T_p \tag{8.7}$$

where,

f_c = Final infiltration rate of the basin area (mm/hr); and
T_p = Maximum allowable ponding time (hr).

Design criteria are set out in Table 8.5.

An infiltration basin is sized to accept the design volume that enters the basin (V_w) plus the volume of rain that falls on the surface of the basin (PA_b) minus the exfiltration volume (fTA_b) out of the bottom of the basin. Based on the analysis, the effective filling time for most infiltration basins (T) will generally be less than two hours. The volume of water that must be stored in the basin (V) is defined as:

$$V = V_w + PA_b - f_d TA_b \tag{8.8}$$

where,

P = Design rainfall event (mm);
A_b = Basin surface area (m^2);
V_w = Design volume that enters the basin (m^3);
T = Effective filling time (hr), generally < 2 ; and
f_d = Design infiltration rate (mm/hr).

For most design storm events, the volume of water due to rainfall on the surface area of the basin (PA_b) is small when compared to the design volume (V_w) of the basin and may be ignored with little loss in accuracy to the final design.

Table 8.5: Design Criteria of Community Infiltration Facilities

Design Parameters	Infiltration Trench	Infiltration Basin
Drainage area	Up to 4ha.	Up to 15ha
Soil investigation requirement	1 soil log test every 15m of trench 1.5m below of the trench bottom	1 soil log test every 500m² of basin area 1.5m below of the basin bottom
Design infiltration rate (f_d)	f_d is equal to $0.5f_c$ with a minimum f_c of 13mm/hr	f_d is equal to $0.5f_c$ with a minimum f_c of 13mm/hr
Maximum drawdown time	24 hours – 10 year ARI	24 hours – 10 year ARI
Runoff treatment	Design ARI for Minor System (Quantity) 40mm (Quality)	Design ARI for Minor System (Quantity) 40mm (Quality)
Backfill material	void space in the range of 30 to 40%	void space in the range of 30 to 40%
Maximum depth	3m with minimum 1.5m above the seasonal groundwater	3m with minimum 1.5m above the seasonal groundwater
Minimum proximity to special facilities or building foundation	7m (downslope) 50m (upslope)	7m (downslope) 50m (upslope)
Overflow route	needs to be identified	needs to be identified
Observation well	1 every 15m of trench length	1 every 50m² of basin area
Spillway and Embankment		Require and should be stabilised and planted with vegetation

The volume of rainfall and runoff entering the basin can be defined in terms of basin geometry. The geometry of a basin will generally be in the shape of an excavated trapezoid with specified side slopes. The volume of a trapezoidal shaped basin may be approximated by:

$$V = \frac{(A_b + A_t)d_b}{2} \qquad (8.9)$$

where,

A_t = Top surface area of the basin (m^2);
A_b = Bottom surface area of the basin (m^2); and
d_b = Basin depth (m).

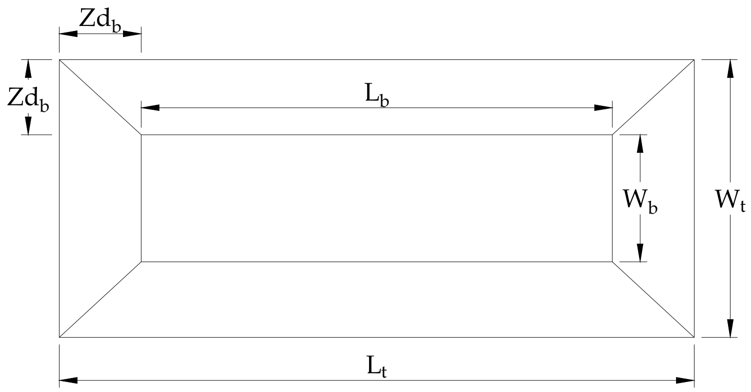
The bottom length and width of the basin may be defined in terms of the top length and width as shown in Figure 8.6:

$$L_b = L_t - 2Z\,d_b \tag{8.10a}$$

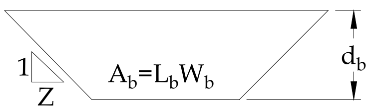
$$W_b = W_t - 2Z\,d_b \tag{8.10b}$$

where,

L_b = Basin bottom length (m);
W_b = Basin bottom width (m);
L_t = Basin top length (m);
W_t = Basin top width (m); and
Z = Specified side slope ratio (H:V).



a) Plan



b) Side

Figure 8.6: Schematic of Basin Nomenclature (Wisconsin Department of Natural Resources, 2004)

By setting Equations 8.8 and 8.9 equal and substituting the above relationships for L_b and W_b, the following equation is derived for the basin top length:

$$L_t = \frac{V_w + Zd_b\left(W_t - 2Zd_b\right)}{W_t d_b - Zd_b^2} \tag{8.11}$$

The infiltration basin usually adopts irregular shape in accordance with grading plan. Sizing is thus based on method described in Chapter on detention basin.

8.3.3.2 Design steps

This involves the following steps:

- Determine the contributed volume of water from the development for storage to meet the runoff control requirement (acceptance criteria).

- Compute the maximum allowable basin depth (d_{max}) from the feasibility equation, $d_{max} = f_c T_p$. Select the basin design depth (d_b) based on the depth that is the required depth above the seasonal groundwater table, or a depth less than or equal to d_{max}, whichever results in the smaller depth

- Compute the basin surface area dimensions for the particular soil type using Equation 8.11. The basin top length (L_t) and width (W_t) must be greater than $2Zd_b$ for a feasible solution. If L_t and W_t are not greater than $2Zd_b$ the bottom dimensions would less than or equal to zero. In this case, the basin depth (d_b) should be reduced for a feasible solution.

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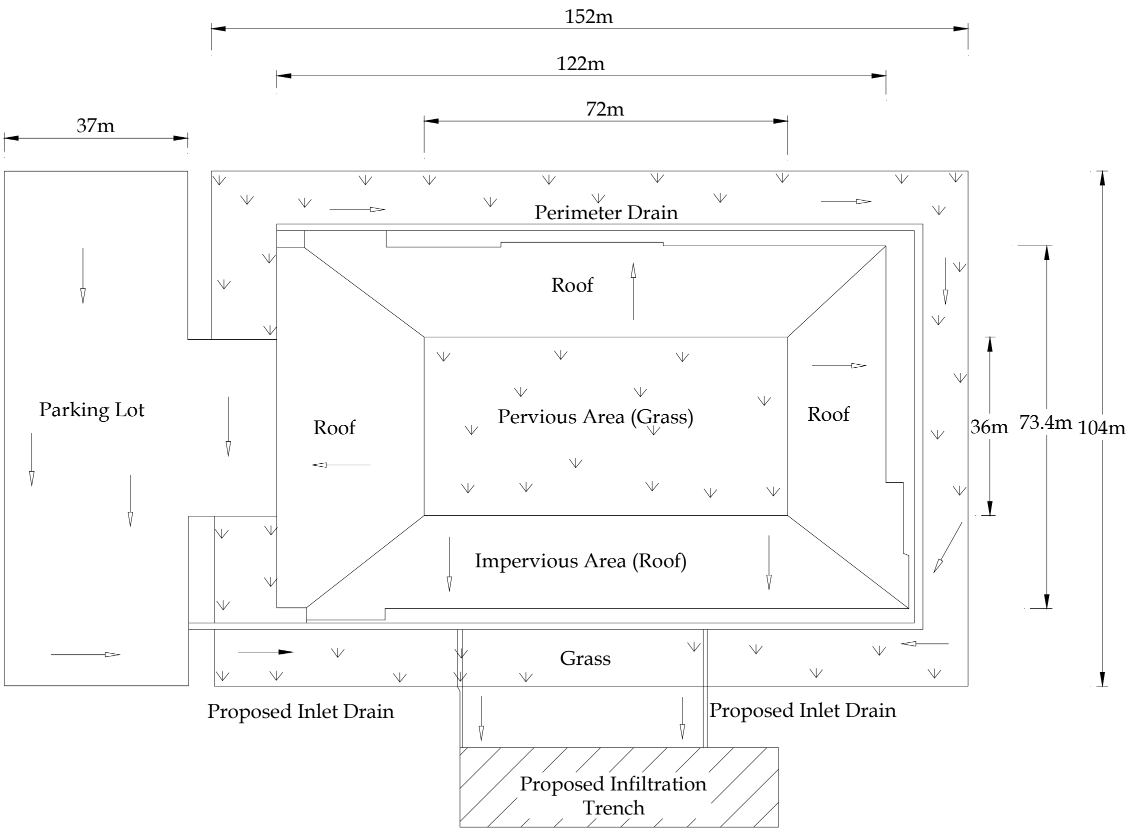
APPENDIX 8.A EXAMPLE – INFILTRATION TRENCH

Problem:

Estimate the preliminary size of an infiltration trench proposed for the USM School of Civil Engineering building in Nibong Tebal, Pulau Pinang with 1.59ha of institutional area. The impervious area is 65% of the catchment area. Given the value of infiltration rate, f = 35 mm/hr, maximum storage time, T_s = 24 hr, effective filling time, T_f = 2 hr and porosity of fill materials, n = 0.35.

a) Site Plan



b) Building and Drainage Layout

Figure 8.A1: Proposed Trench Site and Design

Solution:

Reference	Calculation		Output
	<u>Determine the contributed water quality volume WQV</u>		
Table 2.5	Runoff coefficient for commercial and business centres = 0.95 Runoff coefficient for sport fields, park and agriculture = 0.40 Impervious area = 0.65 Pervious area = 0.35		
Equation 11.1	Required storage for WQV = C_{ave} (P_d) A = (0.65*0.95 + 0.35*0.4)*0.04 x 15900	=	481.8m^3
	where: WQV = Water quality volume C_{ave} = Average rational runoff coefficient (Refer Table 2.5) P_d = Rainfall depth for water quality design storm (= 40 mm) A = Contributing drainage area (ha)		
	<u>Determine of Trench Size</u>		
	Porosity of fill materials, n	=	0.35
	Maximum storage time, T_s (hours)	=	24hr
	Effective filling time, T_f (hours)	=	2hr
	Infiltration rate, f	=	35mm/hr
Equation 8.1	Maximum allowable depth, $d_{max} = \frac{f_c T_s}{n}$		
	$= \frac{0.035 \times 24}{0.35}$	=	2.4m
	Thus, the proposed depth (d_t) of the trench	=	1.0m
	Design infiltration rate (f_d) = 0.5 f_c	=	0.0175m/hr
	$A_t = \frac{V_w}{nd_t + f_d T_f}$		
	$A_t = \frac{481.8}{0.35 \times 1.0 + 0.0175 \times 2.0}$	=	1252m^2
	The dimension of the proposed infiltration trench is should be based on capture of the required water quality volume as 1252m^2	=	50m x 25m x 1m

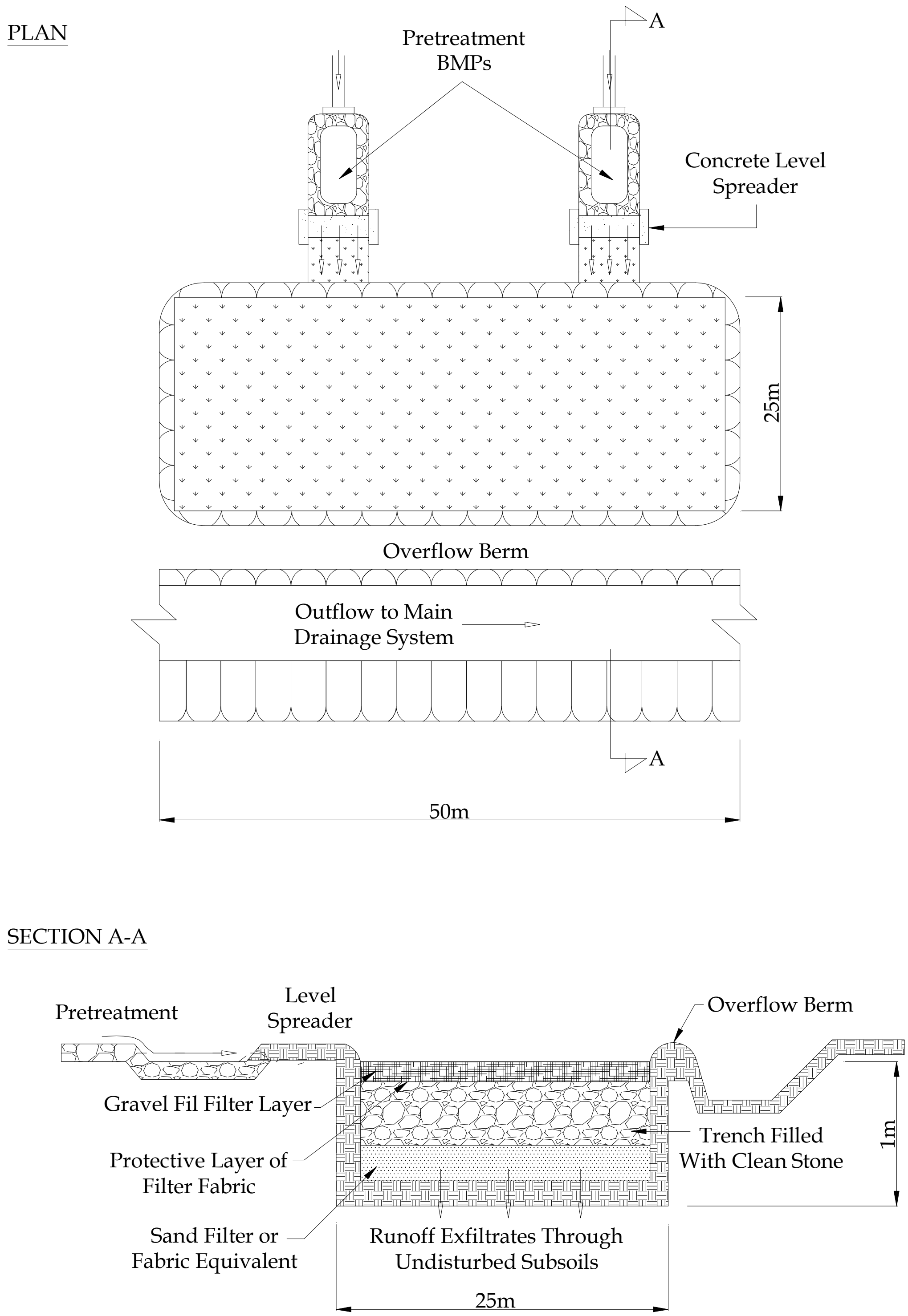


Figure 8.A2: Infiltration Trench Design

APPENDIX 8.B EXAMPLE – INFILTRATION BASIN

Problem:

Estimate the preliminary size of an infiltration basin proposed for the Bertam Perdana, Pulau Pinang. The catchment area is 12.70ha with 52% of impervious area. The site condition of pre-development is palm oil plantations. From initial site investigation, the characteristic of the catchment is as follows:

Soil type	: Sandy loam		
Infiltration capacity (f_c)	: 35mm/hr		
Ground water level	: 3m (below ground surface)		
The following assumptions are made	: Time of concentration pre-development, t_{cs}	= 45 minutes	
	Time of concentrations, t_c	= 30 minutes	
	Porosity of sandy loam, n	= 0.35	
	Maximum storage time, T_s	= 24 hr	
	Effective filling time, T_f	= 2 hr	

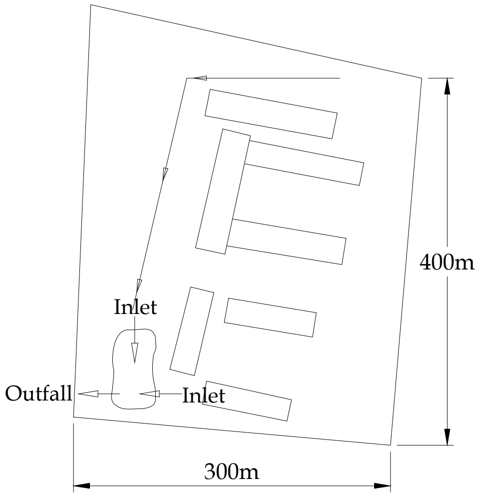


Figure 8.B1: Site Plan

Reference	Calculation	Output
	Determine the contributed water quality volume WQV	
Table 2.5	Runoff coefficient for commercial and business centres = 0.95 Runoff coefficient for sport fields, park and agriculture = 0.40 Impervious area = 0.52 Pervious area = 0.48	
Equation 11.1	Required storage for WQV = C_{ave} (P_d) A = (0.52*0.95 + 0.48*0.4)x0.04 x 127000 =	3484.9m^2
	where: WQV = Water quality volume C_{ave} = Average rational runoff coefficient (Refer Table 2.5) P_d = Rainfall depth for water quality design storm (= 40 mm) A = Contributing drainage area (m^3)	

Reference	Calculation		Output
	<u>Determine of Basin Size</u>		
	Porosity of soil materials, n	=	0.35
	Maximum storage time, T_s (hours)	=	24hr
	Effective filling time, T_f (hours)	=	2hr
	Infiltration rate, f	=	35mm/hr
Equation 8.7	Maximum allowable depth, $(d_{max}) = f_c T_p$ = (35/1000) x 24	=	0.84m
	<u>Thus, the proposed depth (d_b) of the basin</u>	=	0.5m
	The proposed side slope 1:4 (V:H)		
	Design infiltration rate (f_d) = 0.5 f_c = 0.5 x (35/1000)	=	0.00875m/hr
Equation 8.10a	$L_b = L_t - 2Zd_b$		
Equation 8.10b	$W_b = W_t - 2Zd_b$		
Equation 8.11	$L_t = [\ V_w + Zd_b\ (W_t - 2Zd_b)] / [\ W_t\ d_b - Zd_b^2]$		
	V_w is equal to WQV and Say W_t is 100m		
	L_t = [3484.9+(4x0.5)(100 – 2x4x0.5)] / [(100 x 0.5)–(4x0.5²)]	=	75.04m
	The top dimension of the proposed infiltration basin is 100.0m x 72.0m x 0.5m		
	W_b = 75.04–(2x4x0.5)	=	71.04m
	L_b = 100-(2x4x0.5)	=	96m
	The bottom/floor dimension of the proposed infiltration basin	=	96m x 71m

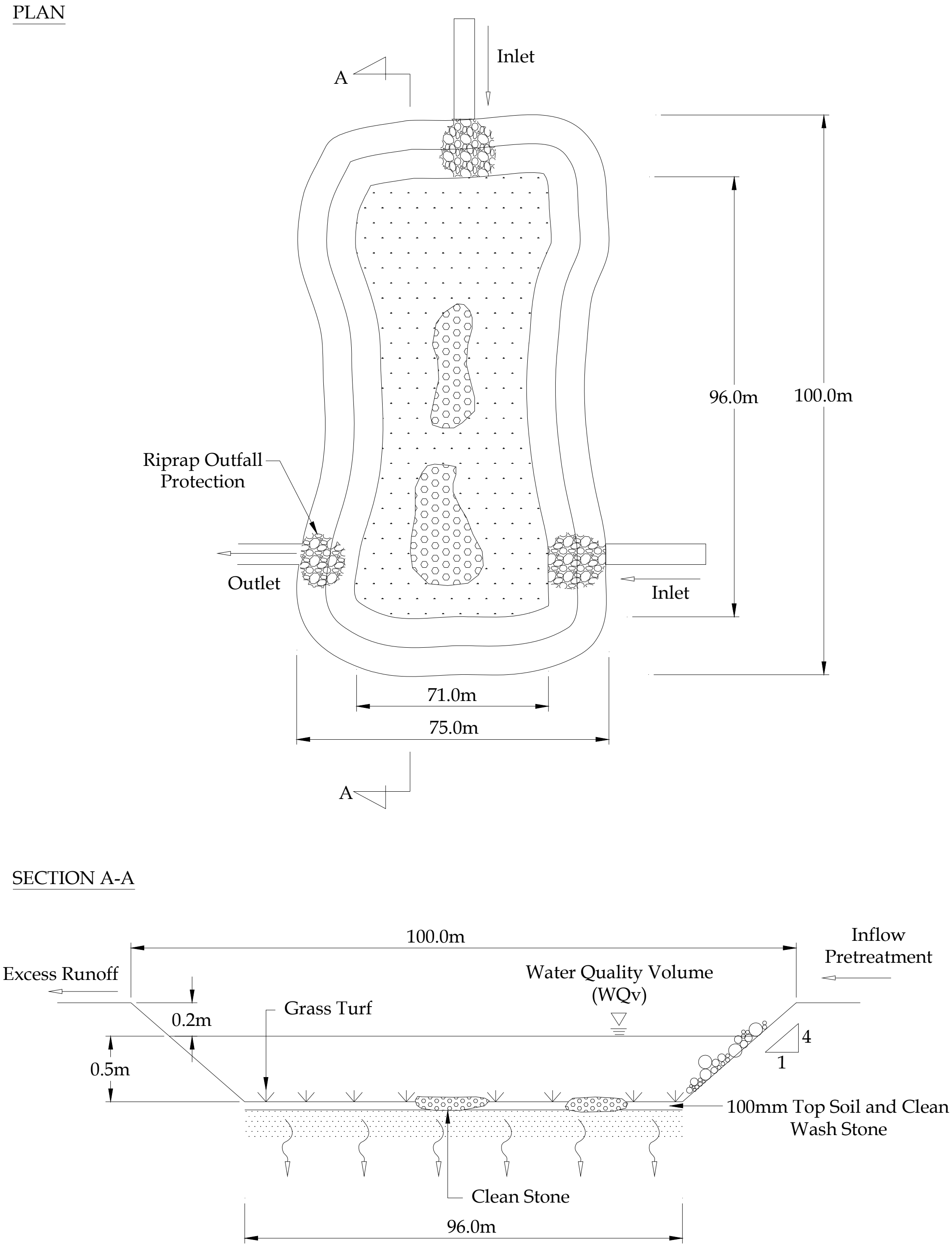


Figure 8.B3: Infiltration Basin Design

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