Chapter 11 **Infiltration measures**

Infiltration system in Adelaide, showing the overflow trench

11.1 Introduction

Stormwater infiltration systems encourage stormwater to infiltrate into surrounding soils (eg Figure 11.1). They are highly dependant on local soil characteristics and are best suited to sandy soils with deep groundwater. All **infiltration measures** require significant pretreatment of stormwater before infiltration to avoid clogging of the surrounding soils and to protect groundwater quality. They result in a reduction in the volume and magnitude of peak **discharges** from impervious areas. *Australian Runoff Quality Guidelines* (Engineers Australia 2003) provides a detailed discussion of procedures for sizing stormwater infiltration systems. This chapter outlines the engineering design of such systems following the selection of a required detention storage volume associated with infiltration.

Not all areas are suited to infiltration systems. Careful consideration of the type of runoff area from which the runoff originates is important to ensure the continued effective operation of these schemes. Australian experience highlights the importance of good design of these systems and the position of these systems in a stormwater **treatment train**. Poor consideration of **catchment** pollutant types and characteristics and site conditions is often the main cause for deteriorating infiltration effectiveness over time because of clogging and lack of appropriate maintenance.

Pretreatment to remove sediments is a vital component in the treatment train and infiltration systems should be positioned as the final element, with its primary function being the discharge of treated stormwater into the surrounding soils and groundwater system.

Soils with low hydraulic conductivities do not necessarily preclude the use of infiltration systems even though the required infiltration/storage area may become unfeasible. However, these soils are likely to render them more susceptible to clogging and require enhanced pretreatment. In addition, standing water for a long period of time may promote algal growth that increases the risk of clogging of the infiltration media. Thus, it is recommended that soil saturated hydraulic conductivities exceeding 1×10^{-5} m/s (36 mm/hr) are most suited for infiltration systems.

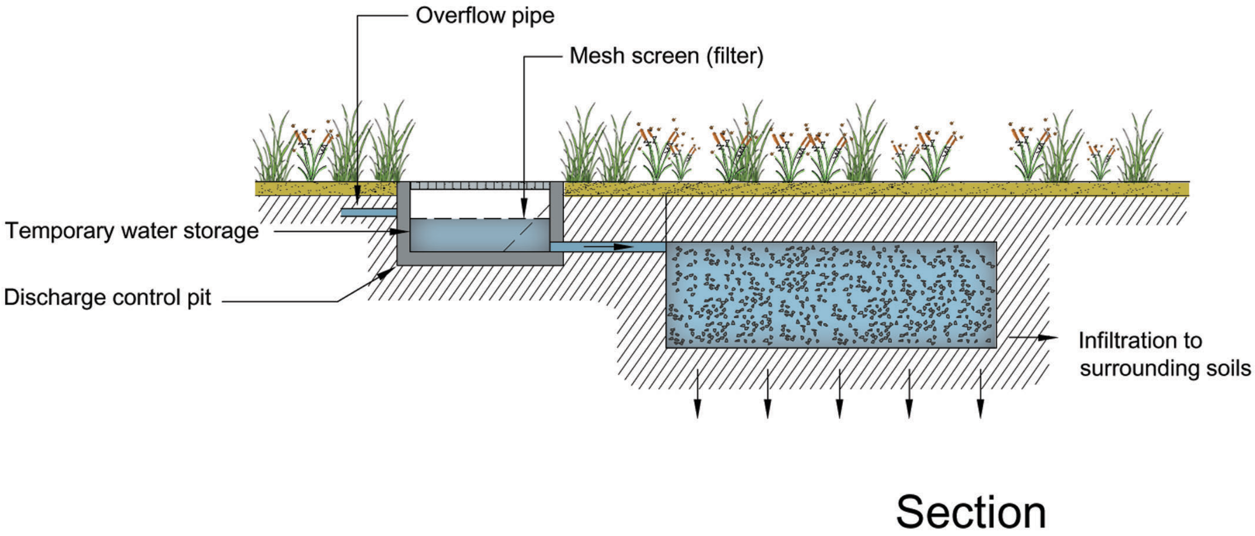

Figure 11.1 Operation of a gravel filled 'soak-away' pit-style infiltration system.

Key factors influencing the operation of an infiltration system are the relationship between infiltration rate, the volume of runoff discharged into the infiltration system, depth to groundwater or bedrock and the available detention storage, that is:

- infiltration rate Q_{inf}) is a product of the infiltration area (A) and the hydraulic conductivity of the *in situ* soil (K_h), i.e. $Q_{inf} = A \times K_h$ m^3/s – therefore, different combinations of infiltration area and hydraulic conductivity can produce the same infiltration rate
- volume of runoff discharged into an infiltration system is a reflection of the catchment area of the system and the meteorological characteristics of the catchment
- detention storage provides temporary storage of inflow to optimise the volume of runoff that can be infiltrated.

The **hydrologic effectiveness** of an infiltration system defines the proportion of the mean annual runoff volume that infiltrates. For a given catchment area and meteorological condition, the hydrologic effectiveness of an infiltration system is determined by the combined effect of the soil hydraulic conductivity, infiltration area and available detention storage. As outlined in Engineers Australia (2003), there are four basic types of detention storages used for promoting infiltration, these being:

- single-size gravel or crushed concrete trenches
- upstand slotted pipes forming 'leaky wells'
- 'milk-crate' type trenches or 'soakaways'
- infiltration basins.

11.2 Verifying size for treatment

The curve (Figure 11.2) shows the relationships between the hydrologic effectiveness, infiltration area and detention storage for a range of soil hydraulic conductivities using Melbourne meteorological conditions. These charts can be used to verify the selected size of a proposed infiltration system.

11.3 Design procedure: infiltration measures

11.3.1 Checking field conditions

Key factors influencing a site's capability to infiltrate stormwater are the soil permeability, soil reactivity to frequent wetting, presence of groundwater and its environmental values, and site terrain.

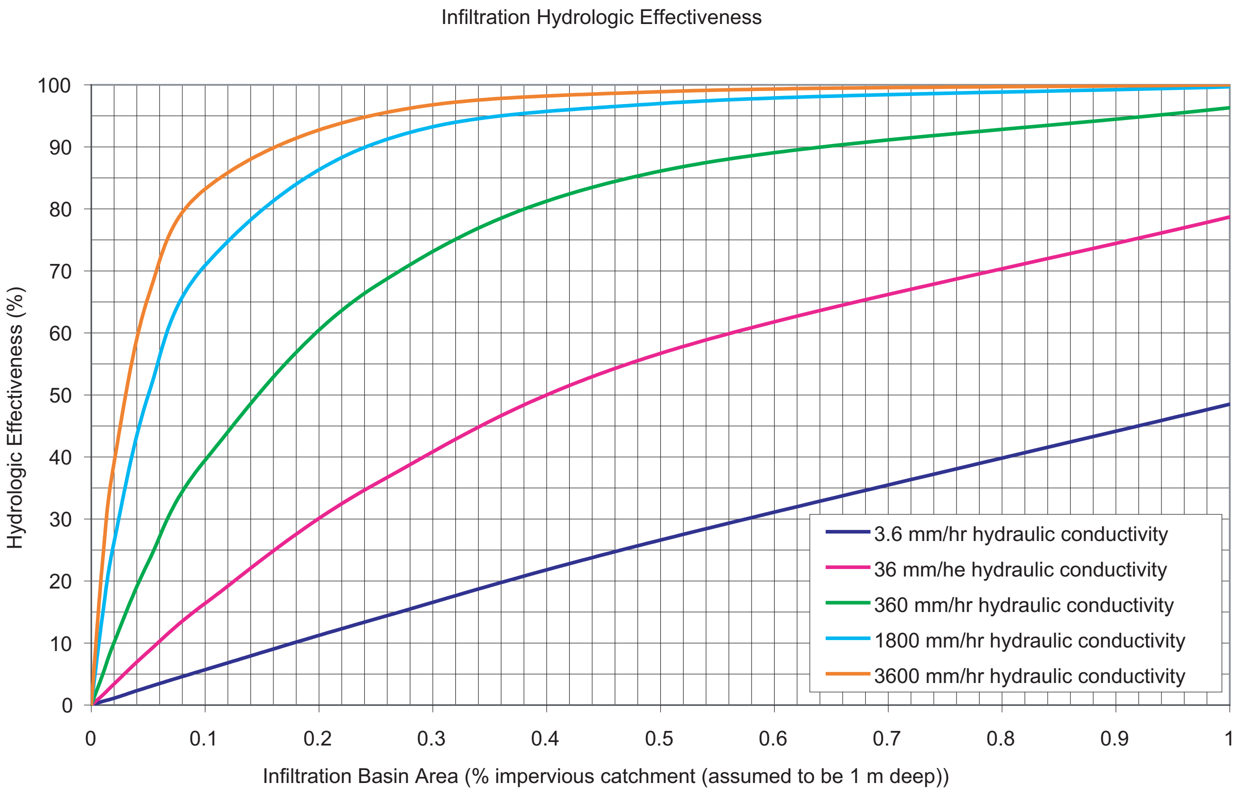

Figure 11.2 Hydrologic effectiveness of detention storages for infiltration systems in Melbourne.

11.3.1.1 Site terrain and soil salinity

A combination of poor soil conditions (e.g. sodic and dispersive soils), steep terrain and shallow saline groundwater can render the use of infiltration systems inappropriate. Dryland salinity is caused by a combination of factors, including leaching of infiltrated water and salt at 'break-of-slope' terrain and the tunnel erosion of dispersive soils. Soil with high sodicity is generally not considered to be suited for infiltration as a means of managing urban stormwater.

Infiltration into steep terrain can result in the stormwater re-emerging onto the surface at some point downstream. The likelihood of this pathway for infiltrated water depends on the soil structure, with duplex soils and shallow soil over rock being situations where re-emergence of infiltrated water to the surface is most likely to occur. This occurrence does not necessarily preclude infiltrating stormwater, unless leaching of soil salt is associated with this process. The provision for managing this pathway will need to be taken into consideration at the design stage.

11.3.1.2 Hydraulic conductivity

Field hydraulic conductivity tests must be undertaken to confirm assumptions of soil hydraulic conductivity adopted during the concept design stage. Field soil hydraulic conductivity (K_h) can be determined using the falling head augerhole method of Jonasson (1984). The range of soil hydraulic conductivities typically determined from a 60-minute falling head period is as follows:

Sandy soil: $K_{60} = 5 \times 10^{-5}$ m/s (180 mm/hr)

Sandy clay: K_{60} = between 1×10^{-5} and 5×10^{-5} m/s (36–180 mm/hr)

Medium clay: K_{60} = between 1×10^{-6} and 1×10^{-5} m/s (3.6–36 mm/hr)

Heavy clay: K_{60} = between 1×10^{-8} and 1×10^{-6} m/s (0.036–3.6 mm/hr)

where K_{60} is the 60-minute value of hydraulic conductivity.

Saturated hydraulic conductivity (K_{sat}) is the hydraulic conductivity of a soil when it is fully saturated. The K_{60} is considered to be a reasonable estimate of K_{sat} for design purposes and can be measured in the field.

Soil is inherently non-homogeneous and field tests can often misrepresent the areal hydraulic conductivity of a soil into which stormwater is to be infiltrated. Field experience has suggested that field tests of 'point' soil hydraulic conductivity can often underestimate the areal hydraulic conductivity of clay soils and overestimate the value for sandy soils. To this end, Engineers

Table 11.1 Moderation factors to convert point to areal conductivities (after Engineers Australia 2003)

Soil type	Moderation factor (U) (to convert 'point' K_h to areal K_h)
Sandy soil	0.5
Sandy clay	1.0
Medium and heavy clay	2.0
K_h = soil hydraulic conductivity	

Australia (2003) recommends that moderation factors (U) for hydraulic conductivities determined from field tests be applied (Table 11.1).

11.3.1.3 Groundwater

Two groundwater issues need to be considered when implementing an infiltration system. The first relates to the environmental values of the groundwater (i.e. the receiving water) and it may be necessary to achieve a prescribed water quality level before stormwater can be discharged. A second design factor is to ensure that the base of an infiltration system is always above the groundwater table and consideration of the seasonal variation of groundwater levels is essential if a shallow groundwater table is likely to be encountered. This investigation should include groundwater mounding (i.e. higher levels very close to the infiltration system) that in shallow groundwater areas could cause problems with nearby structures.

11.3.2 Estimating design flows

11.3.2.1 Design discharges

Two design flows are required for infiltration systems:

- peak inflow to the infiltration system for design of an inlet structure
- major flood rates for design of a bypass system.

Infiltration systems can be subjected to a range of performance criteria including that of peak discharge attenuation and volumetric runoff reduction.

Design discharge for the bypass system is often set at the 100-year ARI event or the discharge capacity of the stormwater conveyance system directing stormwater runoff to the infiltration system.

11.3.2.2 Minor and major flood estimation

A range of hydrologic methods can be applied to estimate design flows. With typical catchment areas discharging to infiltration measures being relatively small (< 1 ha), the **Rational Method** Design Procedure is considered to be a suitable method for estimating design flows.

Figure 11.3 shows an assumed shape of an inflow hydrograph that can be used to estimate the temporary storage volume for an infiltration system. The flow rate shown on the diagram represents a linear increase in flow from the commencement of runoff to the time of concentration (t_c), then this peak flow rate is maintained for the storm duration. Following the

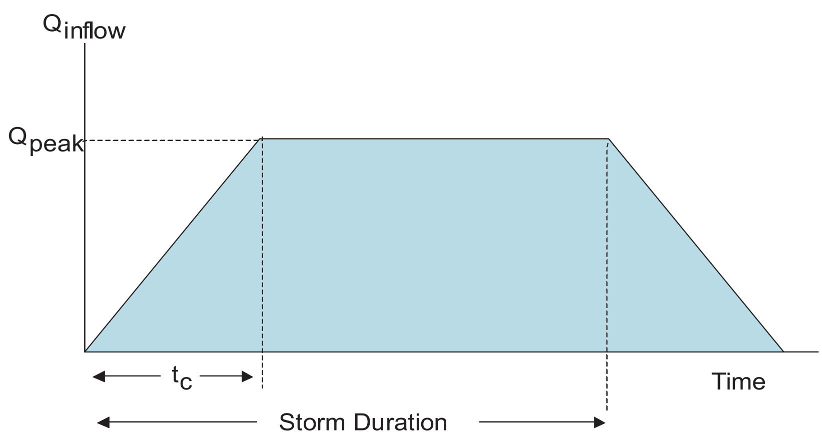

Figure 11.3 Generalised shape of inflow hydrograph.

Table 11.2 Minimum set-back distances
(after Engineers Australia 2003)

Soil type	Saturated hydraulic conductivity m/s (mm/hr)	Minimum distance from structures and property boundaries (m)
Sand	> 5 x 10^{-5} (180)	1.0
Sandy clay	1 x 10^{-5} to 5 x 10^{-5} (36–180)	2.0
Weathered or fractured rock	1 x 10^{-6}–1 x 10^{-5} (3.6–36)	2.0
Medium clay	1 x 10^{-6}–1 x 10^{-5} (3.6–36)	4.0
Heavy clay	1 x 10^{-8}–1 x 10^{-6} (0.036–3.6)	5.0

storm duration the flow rate decreases linearly over the time of concentration. This is a simplification of an urban hydrograph for the purposes of design.

11.3.3 Location of infiltration systems

Infiltration systems should not be placed near building footings to remove the influence of continually wet subsurface or greatly varying soil moisture contents on the structural integrity of these structures. Engineers Australia (2003) recommends minimum distances from structures (and property boundaries to protect possible future buildings in neighbouring properties) for different soil types (Table 11.2).

Identifying suitable sites for infiltration systems should also include avoidance of steep terrain and areas of shallow soils overlying largely impervious rock (non-sedimentary rock and some sedimentary rock such as shale). An understanding of the seasonal variation of the groundwater table is also an essential element in the design of these systems.

11.3.4 Source treatment

Treatment of source water for the removal of debris and sediment is essential and storm runoff should never be conveyed directly into an infiltration system. Pretreatment measures include the provision of leaves and roof litter guards along the roof gutter, sediment sumps, vegetated **swales**, bioretention systems or sand filters.

11.3.5 Sizing the detention storage

There are generally two different methods for determining the size of the detention storage of an infiltration system, i.e. continuous simulation and event-based approaches.

The continuous simulation approach to determining the detention storage volume of an infiltration basin is most suited to meeting design objectives associated with mean annual pollutant load and stormwater runoff volume reduction. This approach uses the hydrologic effectiveness curves as typically shown in Figure 11.1 to determine the size of the infiltration basin on the basis of the percentage of the mean annual runoff infiltrated (hydrologic effectiveness). The design parameters for areas other than Melbourne can be determined from applying the adjustment curves for bioretention systems.

The event-based approach is most suited when the design criteria is based on achieving peak flow reductions as well as volume reduction for pre-specified probabilistic events. The methodology follows that of Argue (2004). The sections below and the worked example present this methodology in greater detail.

11.3.5.1 Storage volume

The required storage volume of an infiltration system is defined by the difference in inflow and outflow volumes for the duration of a storm. The inflow volume is a product of rainfall, contributing area and the runoff coefficient connected to the infiltration system, i.e.

$$\text{Inflow volume } (v_i) \text{ (for storm duration } D, \text{m}^3) = (C \times I \times A \times D)/1000 \qquad \text{(Equation 11.1)}$$

where C is the runoff coefficient as defined in ARR (Institution of Engineers 2001) Book VIII
I is the probabilistic rainfall intensity (mm/hr)
A is the contributing area connected to the infiltration system (m^2)
D is the storm duration (hours).

Outflow from the infiltration system is via the base and sides of the infiltration system and depends on the area and depth of the infiltration system. In computing the infiltration from the walls of an infiltration system, Engineers Australia (2003) suggests that pressure is hydrostatically distributed and thus equal to half the depth of water over the bed of the infiltration system, that is:

$$\text{Outflow volume } (v_o) \text{ (for storm duration } D, \text{m}^3) = \{[(A_{inf}) + (P \times d)/2]\} \times U \times K_h \times D/1000 \quad \text{(Equation 11.2)}$$

where K_h is the 'point' saturated hydraulic conductivity (mm/hr)
A_{inf} is the infiltration area (m^2)
P is the perimeter length of the infiltration area (m)
d is the depth of the infiltration system (m)
U is the 'point' soil hydraulic conductivity moderating factor (see Table 11.1)
D is the storm duration (hours)

Approximations of the required storage volumes of an infiltration system can be computed as follows:

$$\text{Required storage (m}^3) = \{(C \times I \times A) - [(A_{inf}) + (P \times d/2)] \times U \times K_h\}\ D/1000 \quad \text{(Equation 11.3)}$$

Computation of the required storage will need to be carried out for the full range of probabilistic storm durations, ranging from six minutes to 72 hours. The critical storm event is the one which results in the highest required storage. A spreadsheet application is the most convenient way of doing this.

11.3.5.2 Emptying time

Emptying time is defined as the time taken to fully empty a detention storage associated with an infiltration system following the cessation of rainfall. This is an important design consideration as the computation procedure associated with Equation 11.3 assumes that the storage is empty prior to the commencement of the design storm event. Engineers Australia (2003) suggest an emptying time of the detention storage of infiltration systems to vary from 12 hours to 84 hours, depending on the Average Recurrence Interval (ARI) of the design event with the former being more appropriate for frequent events (1 in 3-month ARI) and the latter to less frequent events of 50 years or longer ARI.

Emptying time is computed simply as the ratio of the volume of water in temporary storage (dimension of storage x porosity) to the infiltration rate (hydraulic conductivity × infiltration area).

11.3.6 Hydraulic structures

Two checks of details of the inlet hydraulic structure are required for infiltration systems (i.e. provision of energy dissipation and bypass of above-design discharges). Bypass can be achieved in several ways, most commonly a surcharge pit, an overflow pit or discharge into an overflow pipe connected to a drainage system (see Chapters 5, 6 and 8 for designing a surcharge pit).

11.3.7 Design calculation summary

An *Infiltration System Calculation Checklist* is included to aid the design process of key design elements of an infiltration system.

11.4 Checking tools

Checking aids are included for designers and referral authorities. In addition, advice on construction techniques and lessons learnt from building infiltration systems are provided.

Checklists are provided for:

- design assessments
- construction (during and post)
- operation and maintenance inspections
- asset transfer (following defects period).

11.4.1 Design assessment checklist

The *Infiltration Design Assessment Checklist* presents the key design features that should be reviewed when assessing the design of an infiltration system. These considerations include configuration, safety, maintenance and operational issues that should be addressed during the design phase.

Where an item results in an 'N' when reviewing the design, the design procedure should be assessed to determine the effect of the omission or error.

In addition to the *Checklist*, a proposed design should have all necessary permits for its installation. The referral agency should ensure that all relevant permits are in place. These can include permits to clear vegetation, to dredge, create a waterbody, divert flows or disturb fish or platypus habitat.

Infiltration System — CALCULATION CHECKLIST

CALCULATION TASK	OUTCOME		CHECK
1 Identify design criteria			☐
Design ARI event to be infiltrated (in its entirety)		year	
Or			
Design hydrologic effectiveness		%	
ARI of bypass discharge		year	
2 Site characteristics			☐
Catchment area connected to infiltration system		m^2	
Impervious area connected to infiltration system		m^2	
Site hydraulic conductivity		mm/hr	
Areal hydraulic conductivity moderating factor			
3 Estimate design flow rates			
Time of concentration			
Estimate from flow path length and velocities		minutes	☐
Identify rainfall intensities			
Station used for IFD data:			
Design rainfall intensity for inlet structure(s)		mm/hr	
Design rainfall intensity for overflow structure(s)		mm/hr	☐
Design runoff coefficient			
Inlet structure(s)			☐
Peak design flows			☐
Inlet structure(s)		m^3/s	
Bypass structure(s)		m^3/s	
4 Detention Storage			☐
Volume of detention storage		m^3	
Dimensions		L:W	
Depth		m	
Emptying time		hr	
5 Provision of Pre-treatment			☐
Receiving groundwater quality determined			
Upstream pre-treatment provision			
6 Hydraulic Structures			
Inlet structure			☐
Provision of energy dissipation			
Bypass structure			☐
Weir length		m	
Afflux at design discharge		m	
Provision of scour protection			
Discharge pipe			☐
Capacity of discharge pipe		m^3/s	

Infiltration Design Assessment Checklist					
Bioretention location:					
Hydraulics	Minor flood: (m³/s)		Major flood: (m³/s)		
Area	Catchment area (ha):		Infiltration area (ha)		
Treatment				**Y**	**N**
Pretreatment system sufficient to protect groundwater?					
Infiltration storage volume verified from curves?					
Inlet zone/hydraulics				**Y**	**N**
Station selected for IFD appropriate for location?					
Overall flow conveyance system sufficient for design flood event?					
Velocities at inlet and within infiltration system will not cause scour?					
Bypass sufficient for conveyance of design flood event?					
Basin				**Y**	**N**
Maximum ponding depth will not impact on public safety?					
Maintenance access provided to base of infiltration (where reach to any part of a basin >6 m)?					

Land and asset ownership are key considerations prior to construction of a stormwater treatment device. A proposed design should clearly identify the asset owner and who is responsible for its maintenance. The proposed owner should be responsible for performing the *Asset Handover Checklist* (see Section 11.4.4).

11.4.2 Construction advice

General advice is providedfor the construction of infiltration systems. It is based on observations from construction projects around Australia.

Building phase damage

Protection of infiltration media and vegetation is critical during the building phase as uncontrolled building site runoff is likely to cause excessive **sedimentation**, introduce litter and require replacement of media.

Traffic and deliveries

Ensure traffic and deliveries do not access infiltration areas during construction. Traffic can compact the filter media, cause preferential flow paths and clogging of the surface, deliveries and wash down material can also clog **filtration media**. Infiltration areas should be fenced off during the building phase and controls implemented to avoid washdown wastes.

Timing for engagement

It is critical to ensure that the pretreatment system for an infiltration device is fully operational before flows are introduced into the infiltration media. This will prolong the life of the infiltration system and reduce the risk of clogging.

Inspection wells

It is good design practice to install inspection wells at numerous locations in an infiltration system. This allows water levels to be monitored during and after storm events and infiltration rates can be confirmed over time.

Clean drainage media

Ensure drainage media is washed prior to placement to remove fines and prevent clogging.

11.4.3 Construction checklist

CONSTRUCTION INSPECTION CHECKLIST

Infiltration measures

INSPECTED BY:	
DATE:	
TIME:	
WEATHER:	
CONTACT DURING VISIT:	

SITE: ____________________

CONSTRUCTED BY: ____________________

DURING CONSTRUCTION									
Items inspected	Checked		Satisfactory	Unsatisfactory		Checked		Satisfactory	Unsatisfactory
Preliminary works	Y	N			**Structural components**	Y	N		
1. Erosion and sediment control plan adopted					10. Location and levels of overflow points as designed				
2. Traffic control measures					11. Pipe joints and connections as designed				
3. Location same as plans					12. Concrete and reinforcement as designed				
4. Site protection from existing flows					13. Inlets appropriately installed				
Earthworks					14. Observation wells appropriately installed				
5. Excavation as designed					**Infiltration system**				
6. Side slopes are stable					15. Correct filter media used				
Pre-treatment					16. Fines removed from filter media				
7. Maintenance access provided					17. Inlet and outlet as designed				
8. Invert levels as designed									
9. Ability to freely drain									
FINAL INSPECTION									
1. Confirm levels of inlets and outlets					6. Check for uneven settling of surface				
2. Traffic control in place					7. No surface clogging				
3. Confirm structural element sizes					8. Maintenance access provided				
4. Filter media as specified					9. Construction generated sediment and debri removed				
5. Confirm pre-treatment is working									

COMMENTS ON INSPECTION

ACTIONS REQUIRED

1.
2.
3.
4.
5.
6.

11.4.4 Asset handover checklist

Asset Handover Checklist		
Asset location:		
Construction by:		
Defects and liability period		
Treatment	**Y**	**N**
System appears to be working as designed visually?		
No obvious signs of under-performance?		
Maintenance	**Y**	**N**
Maintenance plans provided for each asset?		
Inspection and maintenance undertaken as per maintenance plan?		
Inspection and maintenance forms provided?		
Asset inspected for defects?		
Asset information	**Y**	**N**
Design Assessment Checklist provided?		
As constructed plans provided?		
Copies of all required permits (both construction and operational) submitted?		
Proprietary information provided (if applicable)?		
Digital files (e.g. drawings, survey, models) provided?		
Asset listed on asset register or database?		

11.5 Maintenance requirements

Maintenance for infiltration systems is focused on ensuring the system does not clog with sediments and that an appropriate infiltration rate is maintained. The most important consideration during maintenance is to ensure the pretreatment is operating as designed.

In addition to checking and maintaining the pretreatment, the *Infiltration Maintenance Checklist* is designed to be used during routine maintenance inspections.

Infiltration Maintenance Checklist			
Inspection frequency: 3 monthly	**Date of visit:**		
Location:			
Description:			
Site visit by:			
Inspection items	**Y**	**N**	**Action required (details).**
Sediment accumulation in pretreatment zone requires removal?			
Erosion at inlet or other key structures?			
Evidence of dumping (e.g. building waste)?			
Evidence of extended ponding times (eg. algal growth)?			
Weeds present within device?			
Clogging of drainage points (sediment or debris)?			
Damage/vandalism to structures present?			
Surface clogging visible?			
Drainage system inspected?			
Resetting of system required?			
Comments:			

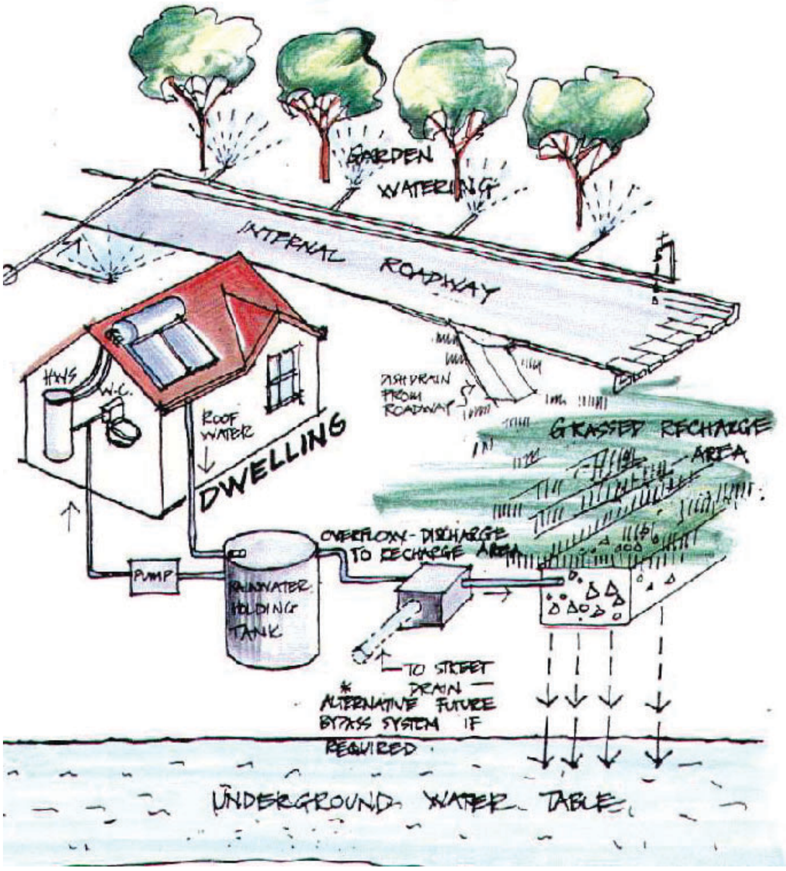

Figure 11.4 A design of an allotment stormwater management scheme (from Urban Water Resource Centre, University of South Australia; http://www.unisa.edu.au/uwrc/ham.htm).

11.6 Infiltration measure worked example

11.6.1 Worked example introduction

An infiltration system is to be installed to treat stormwater runoff from a residential allotment in Venus Bay. As discussed in Engineers Australia (2003), pretreatment of stormwater prior to discharge into the ground via infiltration is essential to ensure sustainable operation of the infiltration system and protection of groundwater. Suspended solids and sediment are the key water quality constituents requiring pretreatment prior to infiltration. Roof runoff is directed into a rainwater tank for storage and to be used as an alternative source of water. Overflow from the rainwater tank can be discharged directly into the gravel trench for infiltration into the surrounding sandy soil without further 'pretreatment'. Stormwater runoff from paved areas will be directed to a pretreatment vegetated swale and then into a gravel trench for temporary storage and infiltration. An illustration of the proposed allotment stormwater management scheme is shown in Figure 11.4.

The allotment in question in this worked example is 1000 m^2 on a rectangular site with an overall impervious surface area of 500 m^2. The site layout is shown in Figure 11.5.

Of the impervious surfaces, roof areas make up a total of 210 m^2, while onground impervious surfaces make up the remaining 290 m^2. There is no formal stormwater drainage system, with stormwater runoff discharging into a small table drain in the front of the property. The design objective of the infiltration system is retention of stormwater runoff from the allotment for events up to, and including, the two-year ARI event. Stormwater flows in excess of the two-year ARI peak discharges are directed towards the road table drain at the front of the property.

Roof runoff is directed to a 5 kL rainwater tank. **Rainwater tanks** can provide significant peak discharge reduction owing to available storage capacity prior to the occurrence of a storm event. In this worked example, the design of the infiltration system involves an assumption that the 5 kL tank will be full in the event of a two-year storm event (owing to the extended period

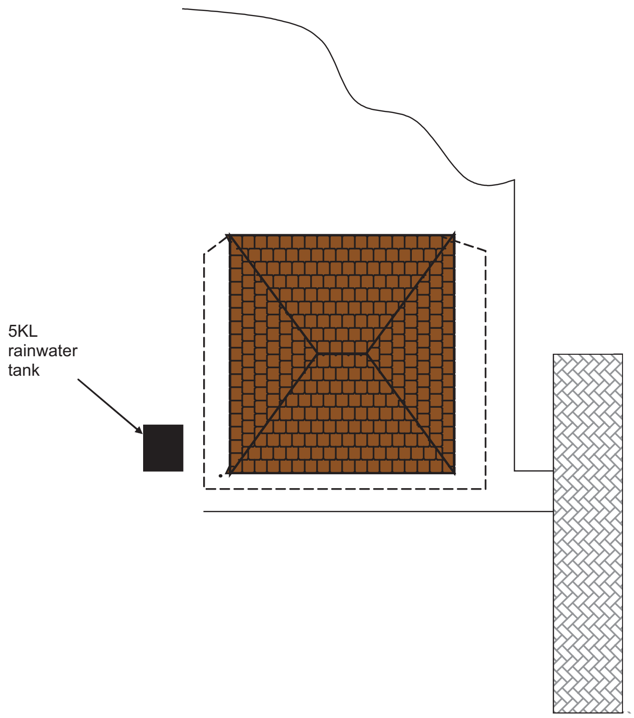

Figure 11.5 Site layout of an infiltration system to treat stormwater runoff from a residential allotment in Venus Bay.

and frequency in which this property will be uninhabited such that the tank water level will not be drawn down as regularly as one associated with a residence that has permanent residents).

The design criteria for the infiltration system are to:

- provide pre-treatment of stormwater runoff
- determine an appropriate size of infiltration system
- ensure that the inlet configuration to the infiltration system includes provision for bypass of stormwater when the infiltration system is operating at its full capacity.

This worked example focuses on the design of the infiltration system and associated hydraulic structures. Analyses to be undertaken during the detailed design phase of the infiltration trench will be based on the procedure outlined in Engineers Australia (2003, chapter 10).

11.6.1.1 Design objectives

The design objectives for an infiltration system are to:

- size infiltration trench to retain the entire runoff volume from the critical (volume) two-year ARI storm event
- design the inlet and outlet structures to convey the peak two-year ARI flow from the critical (flow rate) storm event, ensuring the inlet configuration includes provision for stormwater bypass when the infiltration system is full
- configure the layout of the infiltration trench and associated inlet/bypass structures
- pretreat stormwater runoff
- design appropriate ground cover and terrestrial vegetation over the infiltration trench.

11.6.1.2 Site characteristics

The property is frequently uninhabited and the 5 kL tank will be full for a more significant proportion of time than typical installations. It is assumed that the 5 kL tank will be full at the commencement of the design event. The site characteristics are:

- catchment area 210 m^2 (roof)
  290 m^2 (ground level paved)
  500 m^2 (pervious)
  1000 m^2 (Total)

- landuse/surface type pervious area is either grassed or landscaped with garden beds
- overland flow slope lot is 25 m wide, 40 m deep, slope = 3%
- soil type sandy clay
- saturated hydraulic conductivity (K_h) = 360 mm/hr.

11.6.2 Checking field conditions

Boreholes were drilled at two locations within the site and the results are as follows:

Field tests found the soil to be suitable for infiltration, consisting of fine sand with a saturated hydraulic conductivity of between 360 mm/hr and 1800 mm/hr.

The moderating factor to convert this to the representative areal hydraulic loading is 0.5.

11.6.3 Estimating design flows

The rational method is used to calculate design flows:

- Catchment area = 1000 m^2
  Time of concentration (t_c) ~ 6 min (Institution of Engineers 2001, methods)
- runoff coefficients (Institution of Engineers 2001, Book VIII)
  $^{10}I_1 = 25.6$ mm/hr

  $F_{imp} = 0.5$

  $C_{10}^{1} = 0.1 + (0.7 - 0.1) \times (^{10}I_1 - 25)/(70 - 25) = 0.11$

  $C_{10} = 0.9 \times f + C_{10}^{1} \times (1 - f) = 0.50$
- Runoff coefficients – (Institution of Engineers 2001, Table 8.6)
  $C_2 = 0.43$
  $C_{100} = 0.60$.
- Rainfall intensities (Institution of Engineers 2001, Venus Bay)
  $t_c = 6$ min
  $I_2 = 56.4$ mm/hr
  $I_{100} = 155$ mm/hr
- Rational method

$Q = C.I.A/360$ [$A = 0.1$ ha]
$Q_2 = 0.007$ m^3/s
$Q_{100} = 0.026$ m^3/s.

Design discharges $Q_2 = 0.007$ m^3/s

$Q_{100} = 0.026$ m^3/s

11.6.4 Location of infiltration systems

With a sandy soil profile, the minimum distance of the infiltration system from structures and the property boundary is 1 m. As the general fall of the site is to the front of the property, it is proposed that the infiltration system be sited near the front of the property with paved area runoff directed to grassed **buffers** and a feature vegetated landscaped area adjacent to the infiltration system.

Overflow from the infiltration system will be directed to the table drain of the street in front of the property.

The infiltration system is to be located near the front of the property set back by at least 1 m from the property boundary.

11.6.5 Source treatment

Roof runoff is directed to a rainwater tank. Although the tank may often be full, it nevertheless serves a useful function as a sedimentation basin. This configuration is considered sufficient to provide the required sediment pretreatment for roof runoff.

Calculation of dimensions of soakaways

Location Venus Bay

Catchment area	1000 m²	Infiltration area	16 m²	
Volumetric runoff coefficient	0.55	Perimeter of infiltration area	20 m	
Soil K_h	360 mm/hr	Emptying time	1 hour	OK
Moderating factor	0.5			
Width of infiltration area	2 m			
Length of infiltration area	8 m			
Depth of storage	1 m			
Porosity	0.35			

Storm duration	Storm mean intensity	Volume in	Volume out (during storm duration period)	Storage volume required	Percentage of storage provided	
(minutes)	(mm/hr)	(m³)	(m³)	(m³)	%	
6	56.39	3.101	0.468	2.633	213%	OK
12	42.29	4.652	0.936	3.716	151%	OK
18	34.87	5.754	1.404	4.350	129%	OK
30	26.71	7.345	2.340	5.005	112%	OK
45	21.27	8.774	3.510	5.264	106%	OK
60	17.97	9.884	4.680	5.204	108%	OK
90	14.11	11.641	7.020	4.621	121%	OK
120	11.84	13.024	9.360	3.664	153%	OK
180	9.22	15.213	14.040	1.173	477%	OK
240	7.72	16.984	16.984	0.000		OK
300	6.72	18.480	18.480	0.000		OK
360	6.01	19.833	19.833	0.000		OK
480	5.03	22.132	22.132	0.000		OK
600	4.39	24.145	24.145	0.000		OK
720	3.92	25.872	25.872	0.000		OK
840	3.53	27.181	27.181	0.000		OK
960	3.22	28.336	28.336	0.000		OK
1080	2.98	29.502	29.502	0.000		OK
1200	2.77	30.470	30.470	0.000		OK
1320	2.59	31.339	31.339	0.000		OK
1440	2.44	32.208	32.208	0.000		OK
2160	1.83	36.234	36.234	0.000		OK
2880	1.48	39.072	39.072	0.000		OK
3600	1.24	40.920	40.920	0.000		OK
4320	1.07	42.372	42.372	0.000		OK

Figure 11.6 Spreadsheet for calculating required storage volume of infiltration system (spreadsheet included on CD).

Stormwater runoff from paved areas is directed to a combination of grass buffer areas and a landscape vegetated area which is slightly depressed to provide for trapping of suspended solids conveyed by stormwater. Stormwater overflows from the landscaped area into a grated sump pit and then into the infiltration system.

Pretreatment for sediment removal is provided by:

1. collection of roof runoff into a rainwater tank
2. runoff from the paved area being conveyed to a combination of grassed buffer areas and a landscaped vegetated depression.

11.6.6 Sizing the detention storage

Estimating the required storage volume of the infiltration system involves the computation of the difference in the volumes of stormwater inflow and infiltration outflow according to Equation 11.3. A gravel-filled trench will be used, with a proposed depth of 1 m.

Figure 11.6 shows the spreadsheet developed to undertake the calculations to determine the required dimension of a gravel-filled soakaway trench for the range of probabilistic two-year ARI storm durations. By varying the size (and perimeter) of the infiltration system, at least 100% of required storage is provided for all storm durations.

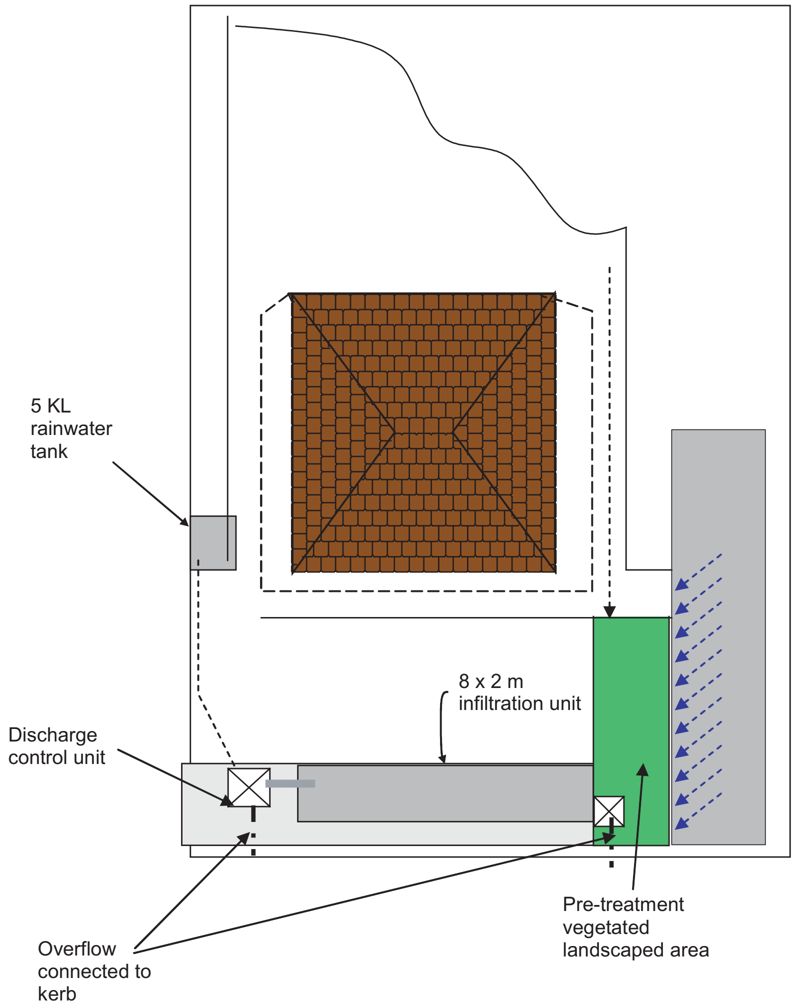

Figure 11.7 Layout of a proposed stormwater infiltration system.

As shown in Figure 11.7, the storm duration that provides the lowest percentage of required storage (above 100%) is a storm duration of 45 minutes (the dimensions of the infiltration device in the spreadsheet have been altered until the storage is greater than 100% for each storm duration). The critical storm duration is 45 minutes and the storage volume requirement 5.3 m^3. With a porosity of a gravel-filled trench estimated to be 0.35, the required dimension of the soakaway is 2 m (width) by 8 m (length) by 1 m (depth). The proposed layout of the infiltration system is shown in Figure 11.7.

11.6.7 Hydraulic structures

11.6.7.1 Inlet design

There are several mechanisms that need to be designed:

- peak two-year ARI design flow
- inlets to the infiltration system
- pipe connections.

Peak two-year ARI design flow is 0.007 m^3/s (calculated in Section 11.6.3) with about 0.003 m^3/s discharging from the rainwater tank overflow and 0.004 m^3/s from other paved areas.

There are two inlets to the infiltration system: from the rainwater tank; and from the driveway (Figure 11.7). These inlets are to be designed to discharge flows up to 0.004 m^3/s each into the infiltration trench with overflows directed to the table drain on the street in front of the property.

Pipe connections from the inlet pits to the infiltration system and street table drain are computed using the orifice flow equation (Equation 11.4)

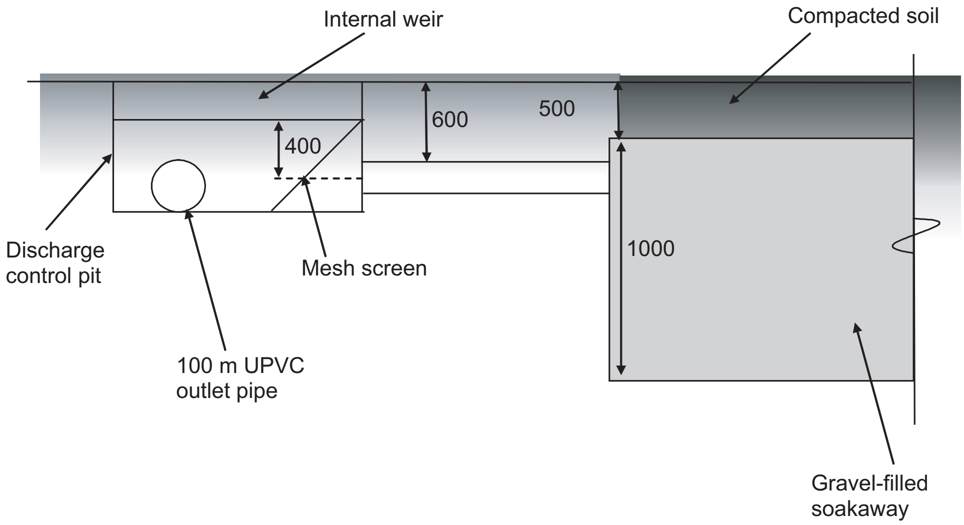

Figure 11.8 Inlet design

$$A_o = \frac{Q}{C_d\sqrt{2gh}} \qquad \text{(Equation 11.4)}$$

C_d = orifice discharge coefficient = 0.6
H = depth of water above the centroid of the orifice (m)
A_o = orifice area (m^2)

For pipe connections to the infiltration system, adopt h = 0.40 m; Q = 0.004 m^3/s. This gives an orifice area of 0.002 m^2, equivalent to a 55 mm diameter pipe → adopt 100 mm diameter uPVC (rigid PVC) pipe (Figure 11.8).

11.6.7.2 Bypass design

An overflow **weir** (internal weir) separates two chambers in the inlet pits: connecting to the infiltration system; and conveying overflows (in excess of the two-year ARI event) to the street table drain. The overflow internal weirs in discharge control pits are to be sized to convey the peak 100-year ARI flow:

Q_{100} = 0.5 × 0.026 m^3/s (two inlet pits) = 0.013 m^3/s

The weir flow equation is used to determine the required weir length:

$$L = \frac{Q}{C_w \Delta H^{1.5}} \qquad \text{(Equation 11.5)}$$

Adopting C =1.7 and H = 0.05 gives
L = 0.7.

Overflow weir will provide at least 150 m freeboard during the peak 100-year ARI flow.

For pipe connection to the street table drain, adopt h = 0.40 m; Q = 0.013 m^3/s. This gives an orifice area of 0.008 m^2, equivalent to a 100 mm diameter pipe → adopt 100 mm diameter uPVC pipe (Figure 11.9).

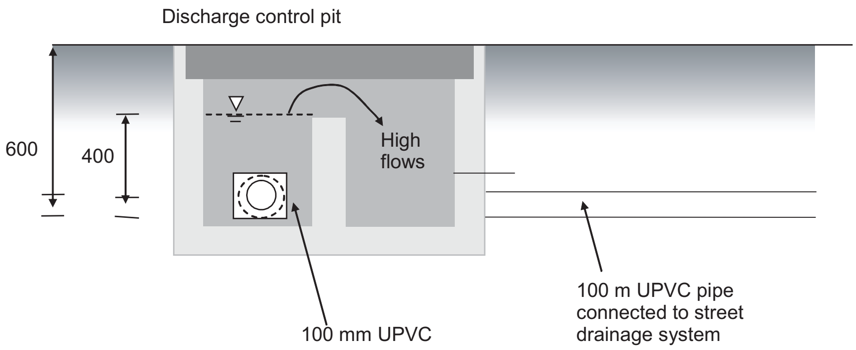

Figure 11.9 Bypass design

11.6.8 Design calculation summary

The completed *Infiltration System Calculation Summary* shows the results of the design calculations.

Infiltration System — CALCULATION SUMMARY

CALCULATION TASK	OUTCOME		CHECK
1 Identify design criteria			✓
Design ARI event to be infiltrated (in its entirety)	2	year	
Design hydrologic effectiveness	N/A	%	
ARI of bypass discharge	100	year	
2 Site characteristics			✓
Catchment area connected to infiltration system	1000	m^2	
Impervious area connected to infiltration system	500	m^2	
Site hydraulic conductivity	360	mm/hr	
Areal hydraulic conductivity moderating factor	0.5		
3 Estimate design flow rates			
Time of concentration			
Estimate from flow path length and velocities	6	minutes	✓
Identify rainfall intensities			
Station used for IFD data:	Venus Bay		
Design rainfall intensity for inlet structure(s)	56.4	mm/hr	
Design rainfall intensity for overflow structure(s)	155	mm/hr	✓
Design runoff coefficient			
Inlet structure(s)	0.43 to 0.60		✓
Peak design flows			✓
Inlet structure(s)	0.004	m^3/s	
Bypass structure(s)	0.013	m^3/s	
4 Detention Storage			✓
Volume of detention storage	5.3	m^3	
Dimensions	8 m x 2 m	L:W	
Depth	1	m	
Emptying time	1	hr	
5 Provision of Pre-treatment			✓
Receiving groundwater quality determined	Y		
Upstream pre-treatment provision	Y		
6 Hydraulic Structures			
Inlet structure			✓
Provision of energy dissipation	Y		
Bypass structure			✓
Weir length	0.70	m	
Afflux at design discharge	0.05	m	
Provision of scour protection	Y		
Discharge pipe			✓
Capacity of discharge pipe	0.013	m^3/s	

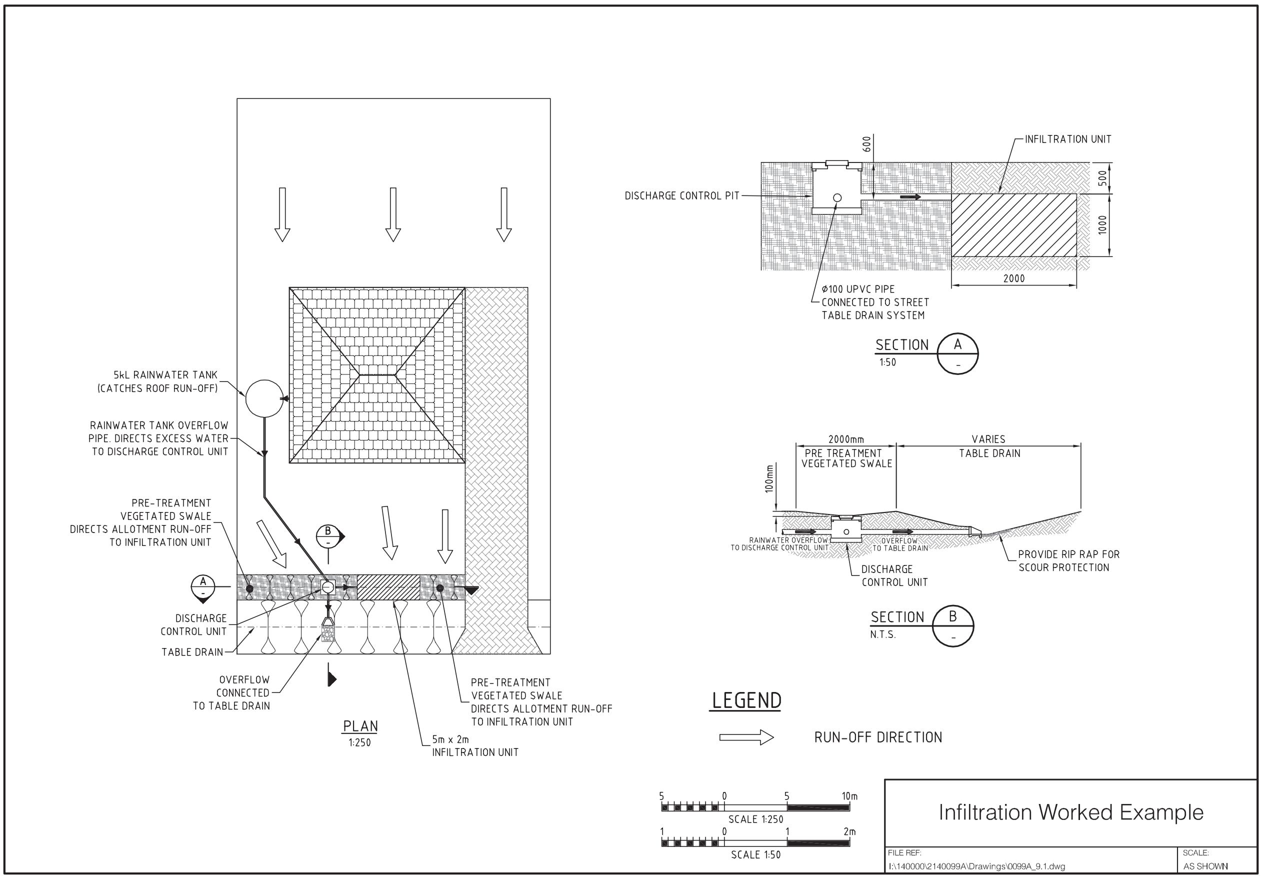

Figure 11.10 Infiltration worked example.

11.6.9 Construction drawing

Figure 11.10 shows the construction drawing for the worked example.

11.7 References

Argue, J.R. (ed) (2004). *Water Sensitive Urban Design: Basic Procedures for 'Source Control' of Stormwater*, Urban Water Resources Centre, University of South Australia.

Engineers Australia (2003). *Australian Runoff Quality Guidelines*, Draft, June.

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Jonasson, S.A. (1984). 'Determination of infiltration capacity and hydraulic conductivity', Proceedings of the 3rd International Conference on Urban Storm Drainage, IAWQ/IAHR, Gothenburg, Sweden.