Chapter 7 **Sand filters**

Sand filters for detention and filtration of stormwater runoff

7.1 Introduction

Sand filters operate in a similar manner as bioretention systems with the exception that they do not support any vegetation owing to the **filtration media** being too free draining (and therefore dries out too frequently to support vegetation). The use of sand filters in stormwater management is suited to confined spaces and where vegetation cannot be sustained (e.g. underground). They are particularly useful treatment devices in heavily urbanised and built-up areas.

Other filter media, such as peat, mulch or gravel have also been used in filtration systems, however, only sand filters are discussed in this chapter.

Key design considerations include the provision of detention storage to yield a high **hydrologic effectiveness** (i.e. allowing for **extended detention** above the filter media), **discharge** control by proper sizing of the perforated underdrain and overflow pathway for above-design operation.

Sand is the filtration media and its hydraulic conductivity ranges from 1×10^{-4} m/s (360 mm/hr) to 1×10^{-3} m/s (3600 mm/hr).

A sand filter system typically consists of three chambers (Figures 7.1 and 7.2).

Water firstly enters a **sedimentation** chamber where gross pollutants and coarse to medium-sized sediment are retained. **Stormwater** enters this chamber either via a conventional side entry pit or through an underground pipe network. The sedimentation chamber can be designed to have either permanent water between events or to drain between storm events with weep holes. There are advantages and disadvantages with each approach.

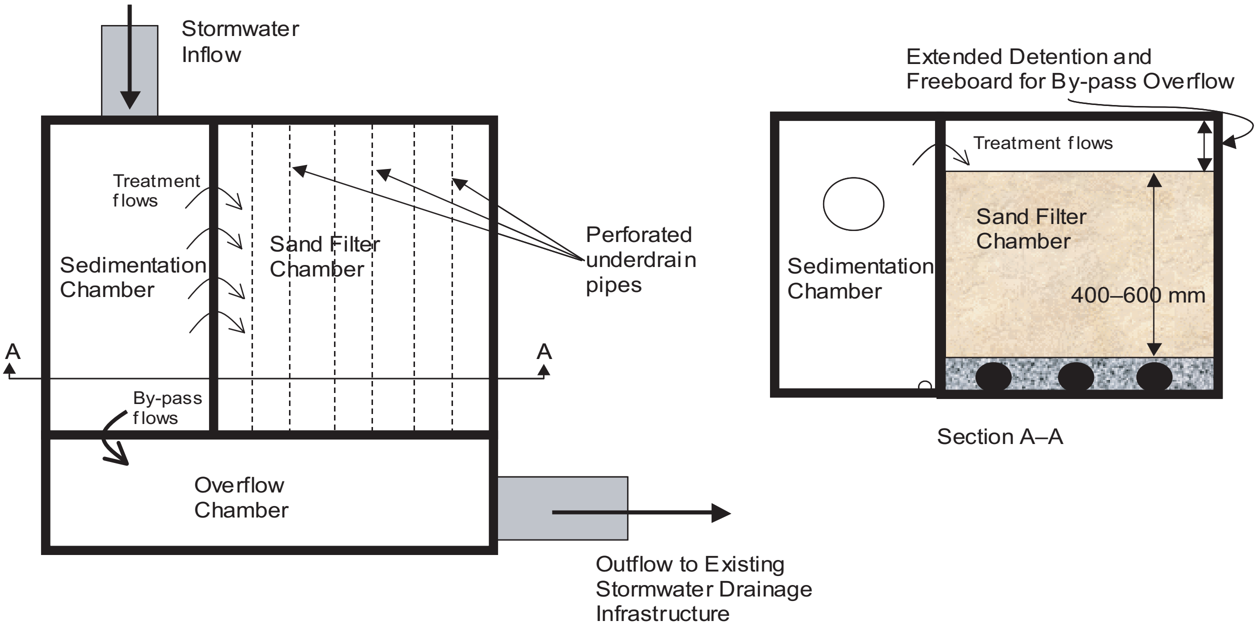


Figure 7.1 Proposed layout of a sand filter.

Having a permanent water body reduces the likelihood of resuspension of sediments at the start of the following rainfall event as inflows do not fall and scour collected sediments. The potential for mosquito breeding is minimised because of the likelihood of sufficient surface oil on incoming flows to discourage mosquitoes. However, this system requires the removal of wet material from the sedimentation chamber during maintenance.

Allowing the sedimentation chamber to drain between events (by installation of weep holes) reduces the likelihood of pollutant transformation during the interevent period. The high organic loads and stagnant water can lead to anaerobic conditions that can also lead to release of soluble pollutants (e.g. phosphorus). Release of these bioavailable pollutants can cause water

Figure 7.2 Underground sand filter for a car park in Auckland, New Zealand.

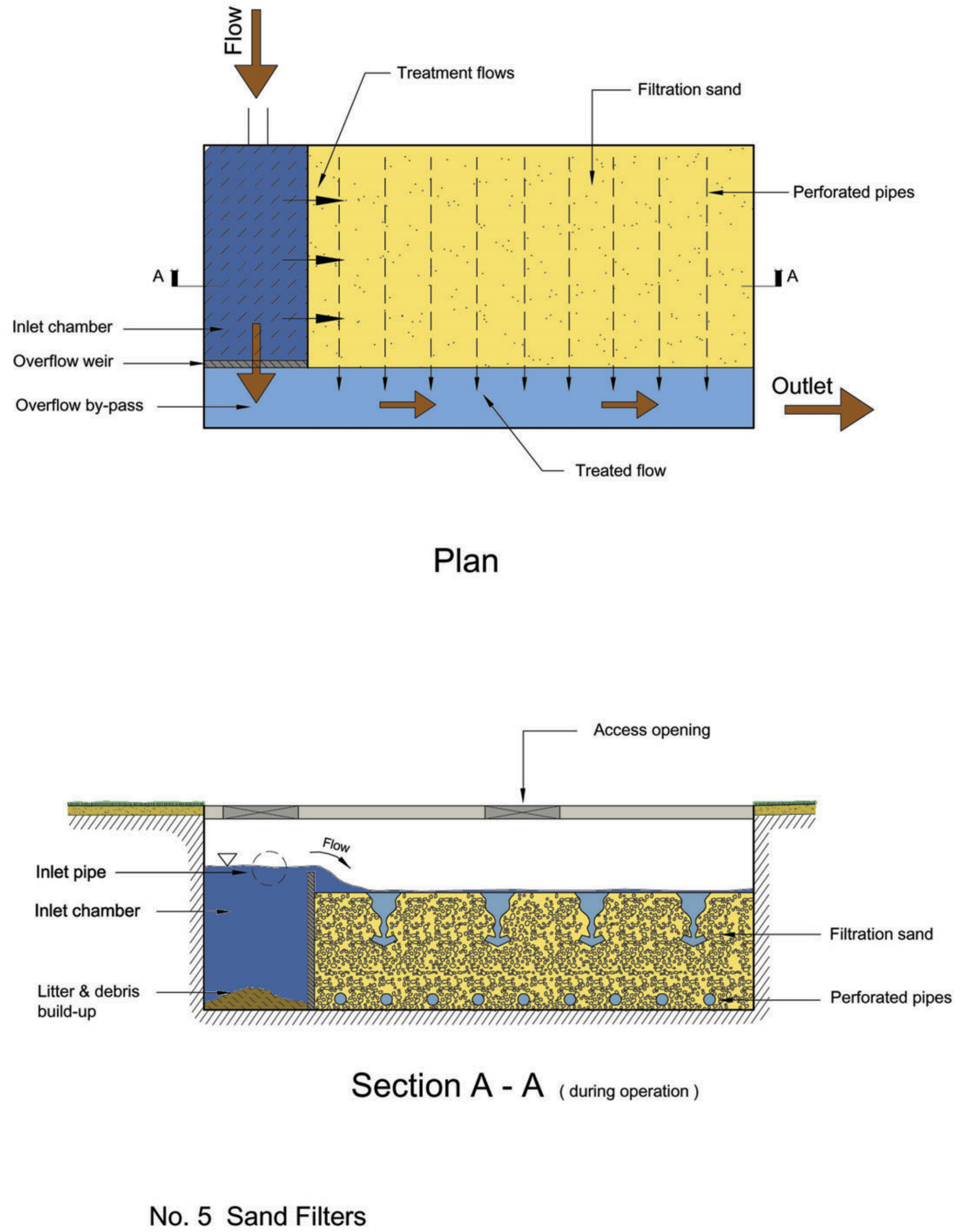


Figure 7.3 A sand filter during operation.

quality problems downstream (e.g. excessive algal growth). The challenge with this system, however, is to design weep holes such that they can continue to drain as material (litter, organic material and sediment) accumulates and the holes do not block.

These factors need to be considered when designing the sedimentation chamber.

Stormwater overflows the sedimentation chamber into a sand filter chamber via a **weir**. Water percolates through the sand filtration media (typically 400 mm–600 mm depth) and filtered water is collected by perforated underdrain pipes in a similar manner as in bioretention systems. A notional extended detention depth is provided within this chamber above which water will flow into an overflow chamber (usually via the sedimentation chamber). Owing to the high saturated hydraulic conductivity of sand as a filtration media, analyses have found that only a small (about 200 mm) extended detention depth is required.

Figure 7.2 shows a sand filter in Auckland and Figure 7.3 illustrates how a sand filter may be configured and operates during storm events.

Key functions of a sand filter include the following:

- capture of gross pollutants
- sedimentation of particles larger than 125 µm within a sedimentation chamber for flows up to a one-year ARI (unattenuated) peak discharge
- filtration of stormwater following sedimentation pretreatment through a sand filtration layer.

7.2 Verifying size for treatment

Figures 7.4, 7.5 and 7.6 show expected performance of sand filters for retention of Total Soluble Solids (TSS), Total Phosphorus (TP) and Total Nitrogen (TN), respectively, for Melbourne conditions. These curves were derived using **Model for Urban Stormwater Improvement Conceptualisation (MUSIC)** (Cooperative Research Centre for Catchment Hydrology 2003) an assumed sand filter depth of 600 mm.

These performance curves can be used to verify the selected size of a proposed sand filter. The regional hydrological design equations for bioretention systems can be used for sand filters.

7.3 Design procedure: sand filters

The following sections describe the design steps required for sand filters.

7.3.1 Estimating design flows

Three design flows are required for sand filters:

- sedimentation chamber design flow – this would normally correspond to the one-year ARI peak discharge as standard practice for sedimentation basins
- sand filter design flow – this is the product of the maximum infiltration rate and the surface area of the sand filter, used to determine the minimum discharge capacity of the underdrains to allow the filter media to freely drain
- overflow chamber design flow – this would normally correspond to the minor drainage system (typically five-year ARI) to size the weir connecting the sand filter to the overflow chamber. This allows minor floods to be safely conveyed and not increase any flooding risk compared to conventional stormwater systems.

7.3.1.1 Minor and major flood estimation

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

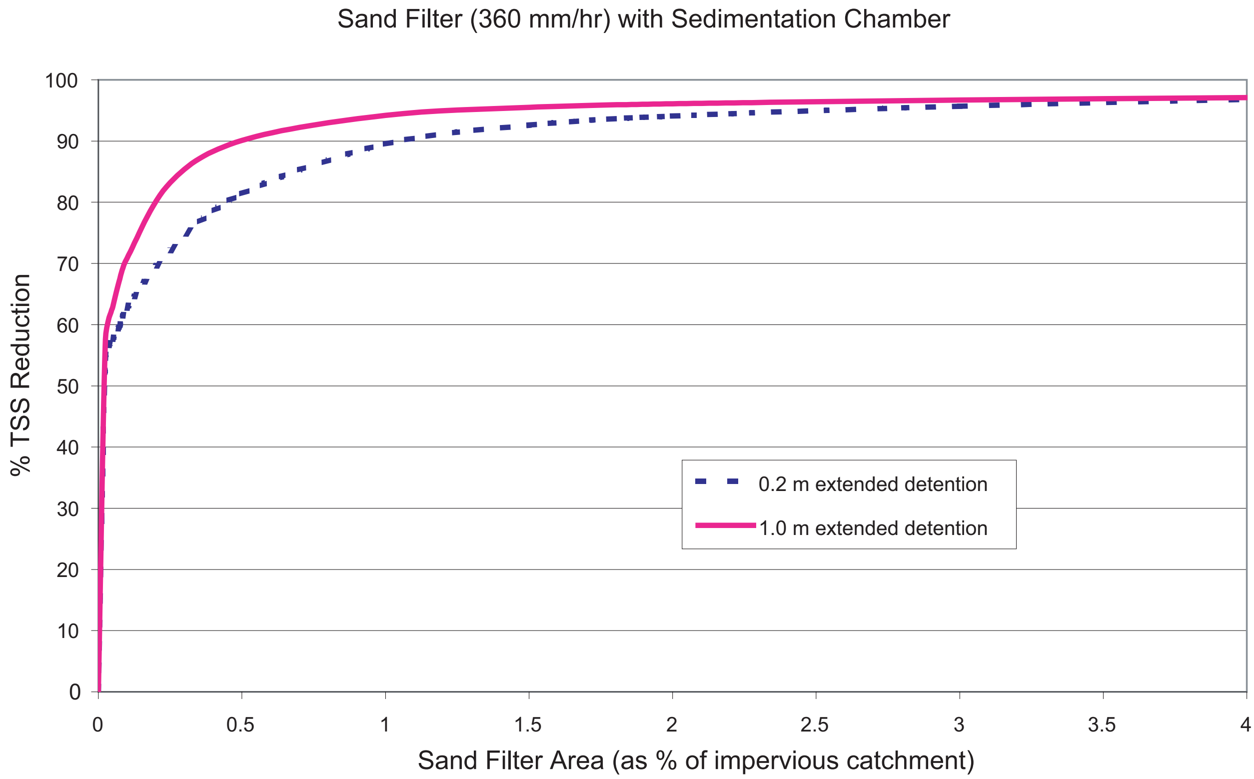
7.3.1.2 Maximum infiltration rate

The maximum infiltration rate represents the design flow for the underdrainage system (i.e. the slotted pipes at the base of the filter media). The capacity of the underdrains needs to be greater than the maximum infiltration rate to ensure the filter media drains freely and the pipe does not become a 'choke' in the system.

A maximum infiltration rate (Q_{max}) can be estimated by applying Darcy's equation:

$$Q_{max} = k \times A \times \frac{h_{max} + d}{d} \qquad \text{(Equation 7.1)}$$

where k is the hydraulic conductivity of the soil filter (m/s)
A is the surface area of the sand filter (m^2)
h_{max} is the depth of pondage above the sand filter (m)
d is the depth of the filter media (m).



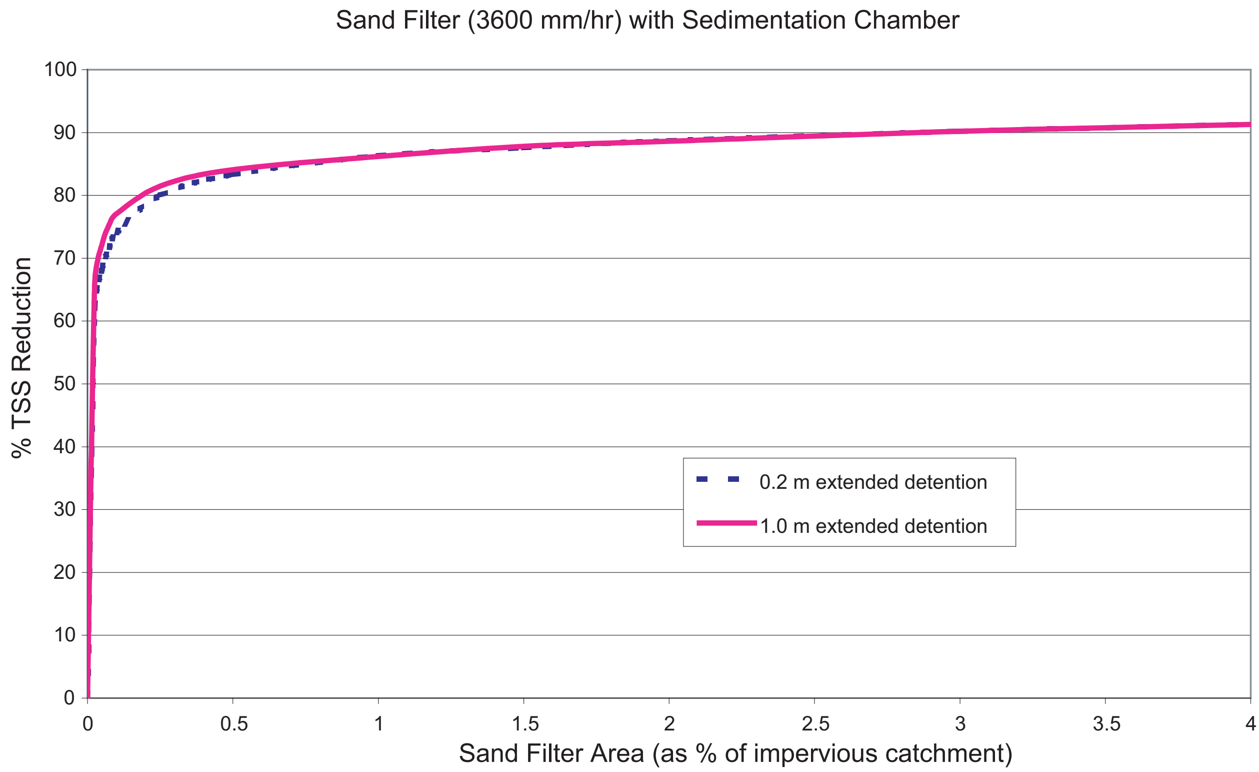
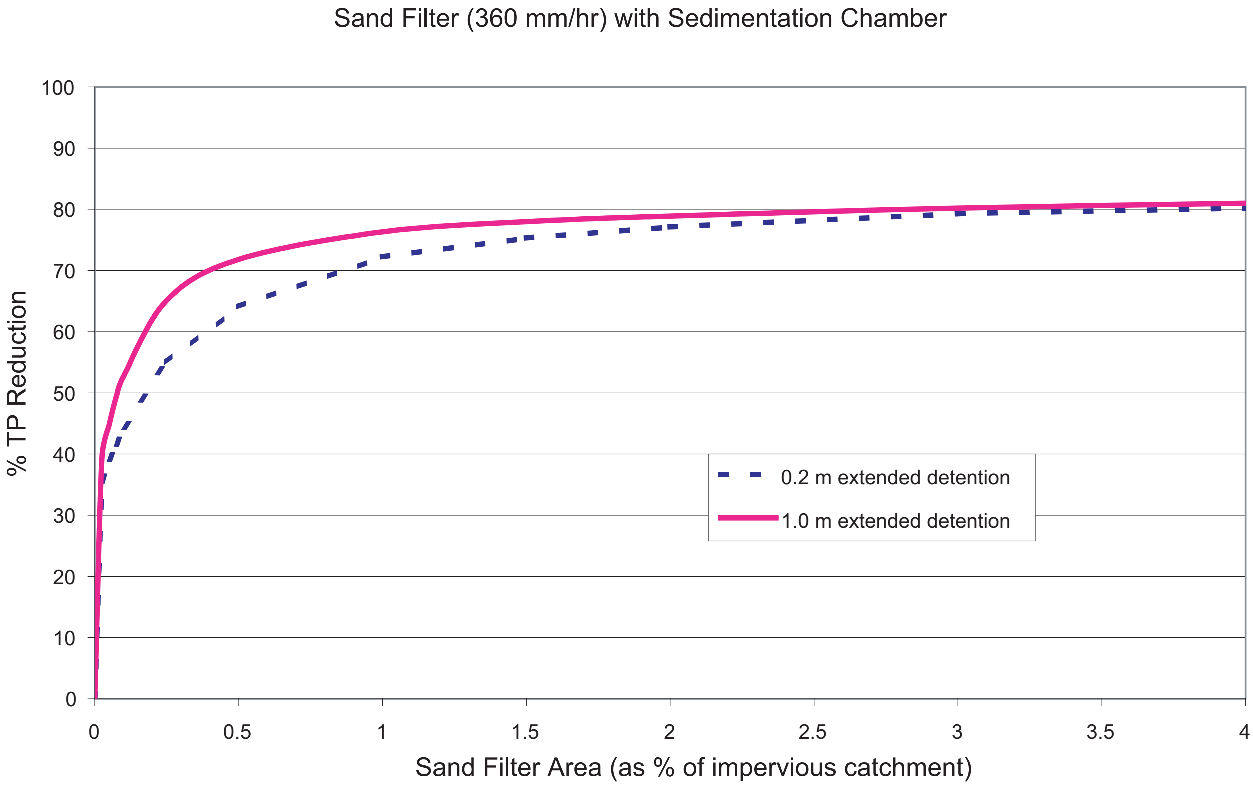


Figure 7.4 Performance of a sand filter in Melbourne in removing total suspended solids in Melbourne.

7.3.2 Hydraulic structure details

7.3.2.1 Sedimentation chamber

Inlet into the sand filter is via the sedimentation chamber. The dimension of this chamber should be sized to retain sediment larger than 125 μm for the design flow and to have adequate capacity to retain settled sediment such that the cleanout frequency is once a year or longer. A



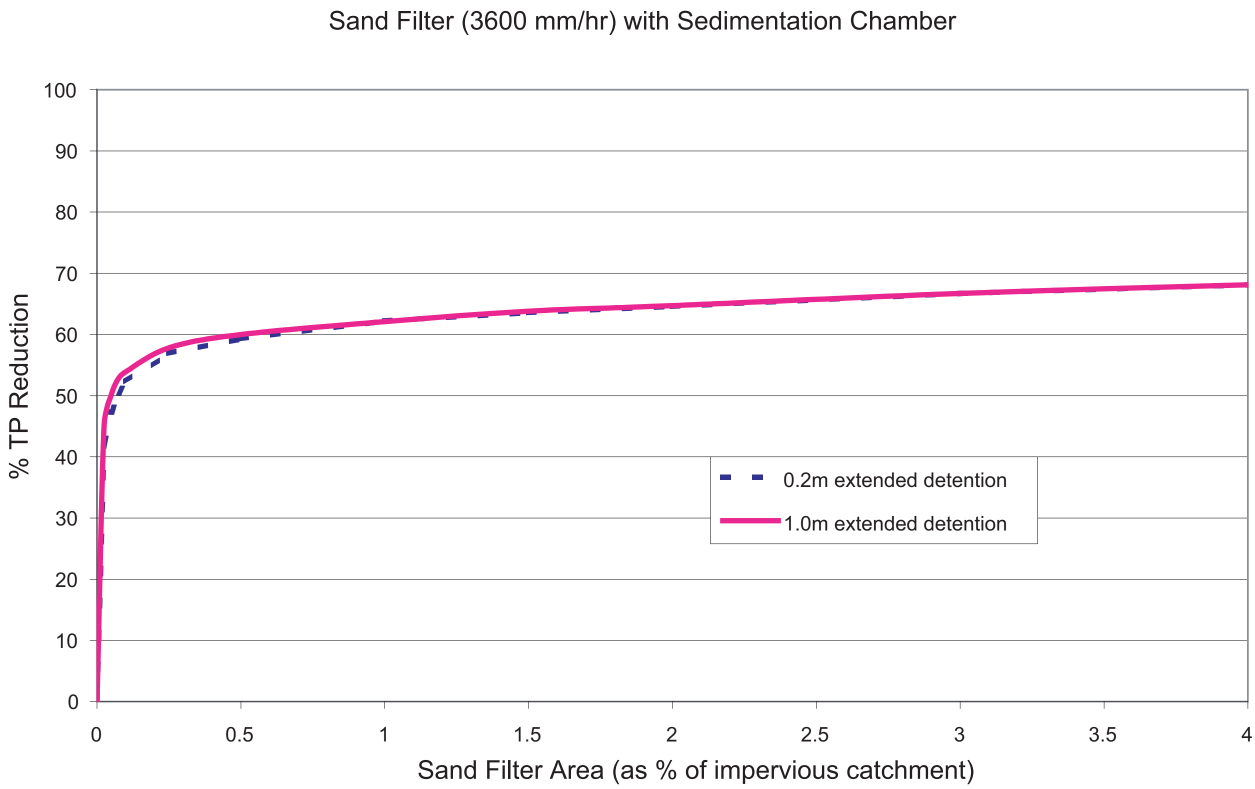
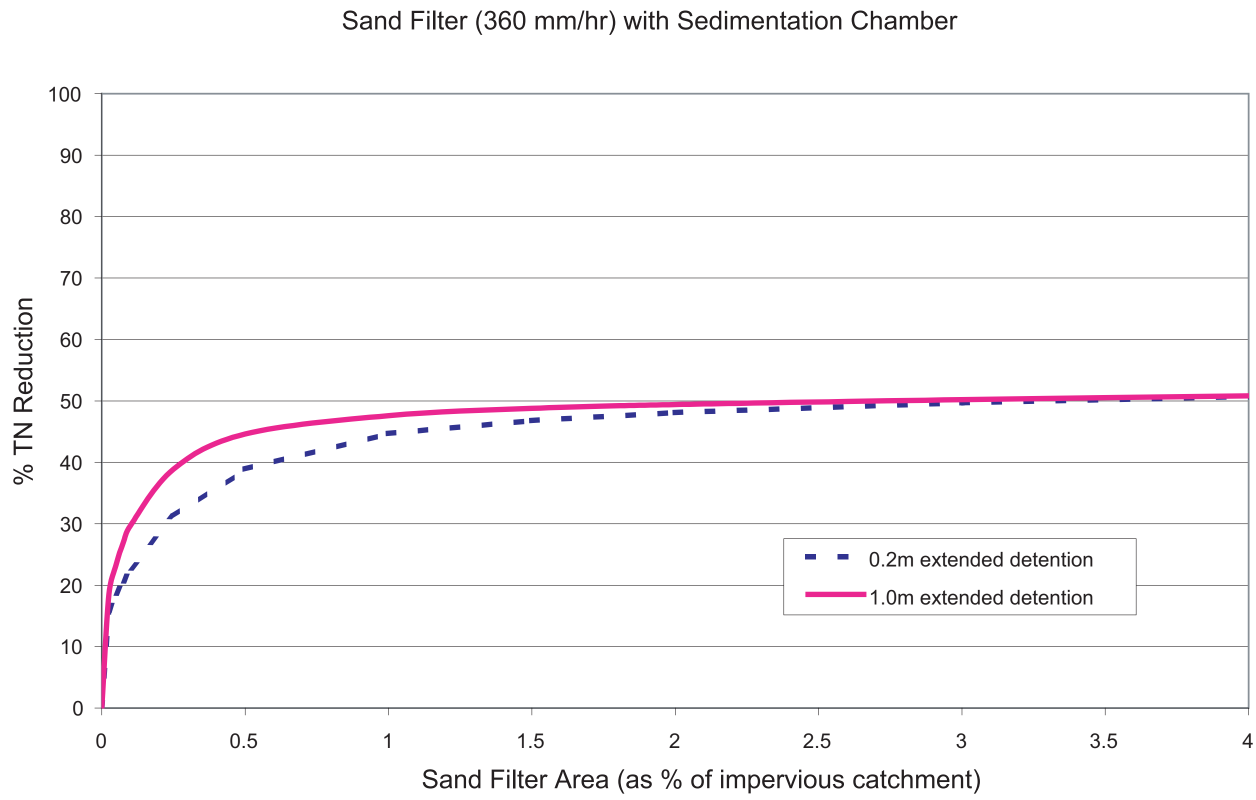


Figure 7.5 Performance of a sand filter in Melbourne in removing TP.

target sediment capture efficient of 70% is recommended. This is lower than the recommendation for sedimentation basins that do not form part of a sand filter (see Chapter 4). With a sand filter, lower capture efficiencies can be supported because of the maintenance regime of the filter media (inspections and either scraping or removal of the surface of the sand filter twice per year) and particle size range in the sand filter being of a similar order of magnitude as the target sediment size of 125 μm. Inspections should also be carried out after



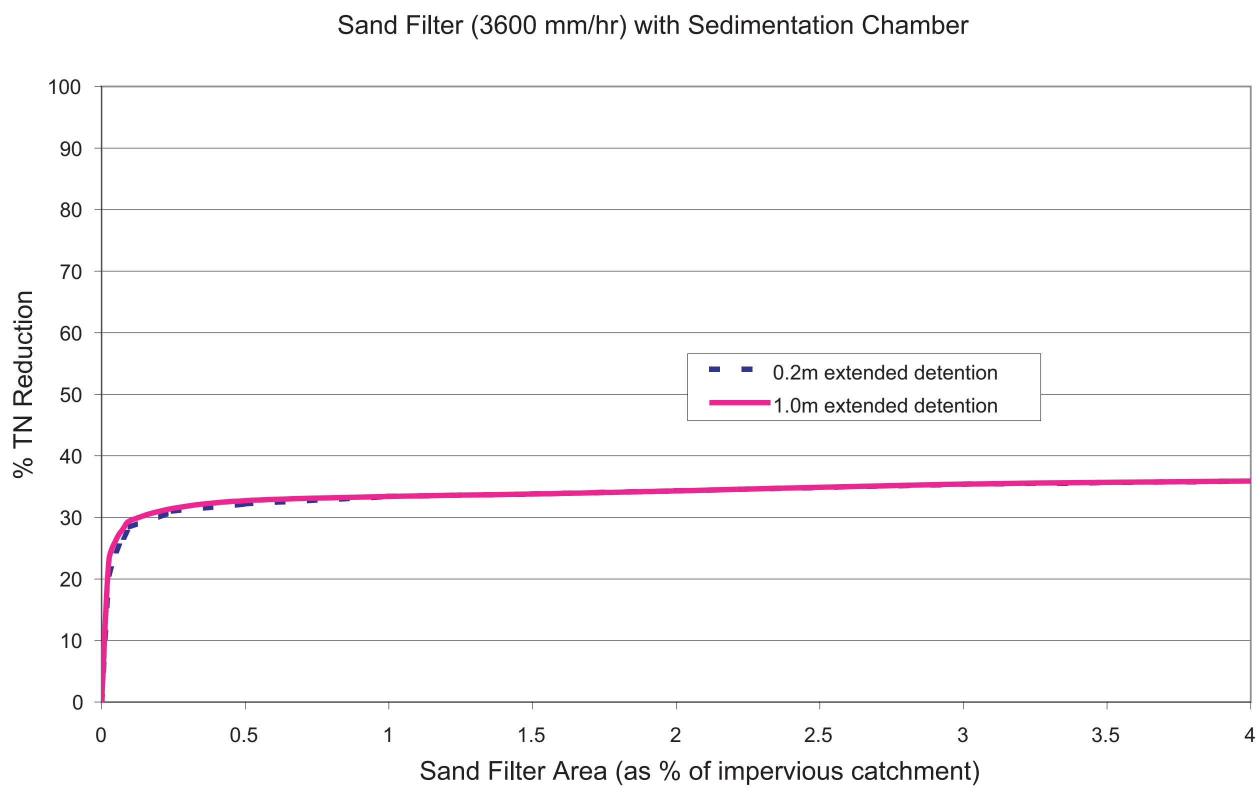


Figure 7.6 Performance of a sand filter in Melbourne in removing total nitrogen (TN).

significant rainfall events soon after the device has been constructed to ensure the sediment and litter loads can be controlled in the sedimentation chamber.

Inspections of the sedimentation chamber would be performed every six months (same as the sand filter); however, sediment clean out may only be required once per year. This will vary from site to site and records of inspections should be kept from each inspection (see Section 7.5.1).

One or more weep holes are also provided when a sedimentation chamber is designed to drain following storm events. Stormwater in the sedimentation chamber is discharged (via surcharge) into the sand filter chamber via a weir during storms. This weir will have a minimum discharge capacity that is equal to the sand filter design flow.

Deposited sediments of the target sediment size or larger should not be resuspended during the passage of the design peak discharge for the overflow chamber. A maximum flow velocity of 0.2 m/s is recommended. Sizing the sedimentation chamber is discussed in Chapter 4.

7.3.2.2 Sand filter chamber

The filter media in the sand filter chamber consist of two layers (i.e. a drainage layer consisting of gravel size material to encase the perforated underdrains and the sand filtration layer). The surface of the sand filter should be set at the crest of the weir connecting the sedimentation chamber to the sand filter chamber. This would minimise any scouring of the sand surface as water is conveyed into the sand filter chamber.

Filter media specifications

A range of particle size ranges can be used for sand filters depending on the likely size of generated sediments. Material with particle size distributions described below has been reported as effective for stormwater treatment, based on Stormwater Management Devices (Auckland Regional Council 2003):

Percentage passing	9.5 mm	100%
	6.3 mm	95%–100%
	3.17 mm	80%–100%
	1.5 mm	50%–85%
	0.8 mm	25%–60%
	0.5 mm	10%–30%
	0.25 mm	2%–10%

Alternatively finer material can be used (e.g. Unimin 16/30 FG sand, details below); however, this requires more attention to maintenance to ensure the material maintains its hydraulic conductivity and does not become blocked. Inspections should be carried out every three months during the initial year of operation as well as after major storms to check for surface clogging.

Percentage passing	1.4 mm	100%
	1.0 mm	80%
	0.7 mm	44%
	0.5 mm	8.4%.

This grading is based on a Unimin 16/30 FG sand grading.

Drainage layer specifications

The drainage layer specification can be either coarse sand or fine gravel, such as a 5 mm or 10 mm screenings. Specification of the drainage layer should take into consideration the perforated pipe system, in particular the slot sizes. Fine gravel should be used if the slot sizes are large enough for the sand to be washed into the slots.

This layer should be a minimum of 150 mm and preferably 200 mm thick.

Impervious liner requirements

Sand filters are considered as conveyance filtration devices rather than infiltration systems. Stormwater is treated via filtration through a specified soil media with the filtrate collected via a subsurface drainage system to be either discharged as treated surface flow or collected for reuse. The amount of water lost to surrounding soils depends largely on local soils and the hydraulic conductivity of the filtration media in the sand filter.

Where sand filters are installed near to significant structures care should be taken to minimise any leakage from the sand filter. The surrounding soils should be tested, including those on the typical hydraulic conductivity.

Should surrounding soils be very sensitive to any seepage from sand filters (e.g. sodic soils, shallow groundwater or close proximity to significant structures), it is necessary to ascertain if the saturated hydraulic conductivity of the surrounding soils is less than one order of magnitude of the filtration media. If this is the case, an impervious liner can be used to contain all water within the sand filter. The liner could be a flexible membrane or a concrete casing. A leakage test should be done immediately after construction to ensure that leakage from the filter does not occur.

7.3.2.3 Overflow chamber

The overflow chamber conveys excess flow to downstream drainage infrastructure and the overflow weir should be sized to ensure that it has sufficient capacity to convey the design discharge from the sedimentation chamber. The overflow weir should be located in the sedimentation chamber.

When water levels in the sedimentation and sand filter chambers exceed the extended detention depth, water will overflow into the overflow chamber and be conveyed into the downstream drainage system. Water levels in the overflow chamber should ideally be lower than the crest of the overflow weir although some level of weir submergence is not expected to severely reduce the discharge capacity of the overflow weir. Water levels should remain below ground when operating at the design discharge for the minor stormwater drainage system.

A broad-crested weir equation can be used to determine the length of the overflow weir:

$$Q_{\text{weir}} = C_{\text{w}} \times L \times H^{1.5} \qquad \text{(Equation 7.2)}$$

where Q_{weir} = flow over the weir
C_{w} is the weir coefficient (~1.7)
L is the length of the weir (m)
H is the **afflux** (m)

7.3.3 Size of slotted collection pipes

Either flexible perforated pipes (e.g. AG pipe) or slotted PVC pipes can be used for the collection pipes; however, care needs to be taken to ensure the slots in the pipes are not so large that sediment would freely flow into the pipes from the drainage layer. The slotted or perforated collection pipes at the base of the sand filter collect treated water for conveyance to downstream drainage infrastructure. They should be sized so that the filtration media are freely drained and the collection system does not become a 'choke' in the system. There are, however, circumstances where it may be desirable to restrict the discharge capacity of the collection system so as to promote a longer detention period within the sand media. One such circumstance is when depth constraints may require a shallower filtration depth and a larger surface area, leading to a higher than desired maximum infiltration rate.

Treated water that has passed through the filtration media is directed into slotted pipes via a 'drainage layer' (typically fine gravel or coarse sand, 2 mm–10 mm diameter). The purpose of the drainage layer is to efficiently convey treated flows into the collection pipes while preventing any of the filtration media from being washed downstream.

It is considered reasonable for the maximum spacing of the slotted or perforated collection pipes to be 1.5 m (centre to centre) so that the distance water needs to travel through the drainage layer does not hinder drainage of the filtration media.

Installing parallel pipes is a means to increase the capacity of the collection pipe system. A 100 mm diameter is considered to be a maximum size for the collection pipes.

To ensure the slotted or perforated pipes are of adequate size several checks are required:

- the perforations (slots) are adequate to pass the maximum infiltration rate (or the maximum required outflow)
- the pipe itself has sufficient capacity
- the drainage layer has sufficient hydraulic conductivity and will not be washed into the perforated pipes.

7.3.3.1 Perforations inflow check

To estimate the capacity of flows through the perforations ($Q_{perforations}$), orifice flow conditions are assumed and a sharp-edged orifice equation can be used (Equation 7.3). First, the number and size of perforations needs to be determined (typically from manufacturer's specifications) and used to estimate the flow rate into the pipes using a head of the filtration media depth plus the ponding depth. Second, it is conservative but reasonable to use a blockage factor (*B*) (e.g. 50%–75% blocked) to account for partial blockage of the perforations by the drainage layer media.

$$Q_{perforations} = B \times C \times A_{perforation}\sqrt{2gh} \qquad \text{(Equation 7.3)}$$

where $Q_{perforations}$ is the capacity of flows through the perforations
B is the blockage factor (0.5–0.75)
C is the orifice coefficient (about 0.6)
A is the area of the perforation
h is depth of water over the collection pipe.

The combined discharge capacity of the perforations in the collection pipe should exceed the design discharge of the sand filter unless the specific intention is to increase detention time in the sand filter by limiting the discharge through the collection pipe.

Prevention of clogging of the perforations is essential and a drainage layer consisting of gravel encasing the slotted pipe is recommended.

7.3.3.2 Perforated pipe capacity

The discharge capacity of the collection pipe (Q_{pipe}) can be calculated simply using an orifice flow equation similar to Equation 7.3:

$$Q_{pipe} = C \times A_{pipe}\sqrt{2gh}$$

The capacity of this pipe needs to exceed the maximum infiltration rate.

7.3.4 Design principles to facilitate maintenance

There are several key decisions during the design process that have significant effect on the ability to perform maintenance on a sand filter. As sand filters do not support vegetation, maintenance is paramount to performance, especially in maintaining the porosity of the surface of the sand filtration media.

Easy access is the most important maintenance consideration during design. This includes both access to the site (e.g. traffic management) as well as access to the sedimentation and sand filter chambers (as well as less frequent access to the overflow chamber). Regular inspections are also required, particularly following construction and should be conducted following the first several significant rainfall events. This reinforces the requirement for easy access to the site.

Access into the sand filter chamber is particularly important because of the requirement to remove the fine sediments from the surface layer of the sand filter (top 25 mm–50 mm) from the entire surface area when accumulated fine sediment forms a 'crust'. This may require multiple entry points to the chamber depending in the scale of the filter. If maintenance crews cannot access part of the sand filter chamber, it will quickly become blocked and be unable to improve water quality.

The sedimentation chamber is required to be drained for maintenance purposes (regardless of whether it is designed to drain between storm events). A drainage valve that can drain this chamber needs to be designed into systems that have no weep holes. Having freely drained material significantly reduces the removal and disposal costs from the sedimentation chamber.

The perforated collection pipes at the base of the sand filter are also important maintenance considerations. Provision should be made for flushing (and downstream capture of flushed material) of any sediment build-up that occurs in the pipes. This can be achieved with solid pipe returns to the surface for inspection openings (at the upstream end of the pipes) and a temporary filter sock or equivalent placed over the outlet pipe in the overflow chamber to capture flushed sediment.

7.3.5 Design calculation summary

A *Sand Filters Calculation Checksheet* is included for the key design elements to aid the design process.

Sand Filters	CALCULATION CHECKLIST	
CALCULATION TASK	**OUTCOME**	**CHECK**
1 Identify design criteria		
Conveyance flow standard (ARI)		year
Treatment flow rate (ARI)		year
Pretreatment objective		μm
Sand filter area		m^2
Sand filter depth		m
Maximum ponding depth		mm ☐
2 Catchment characteristics		
Area		m^2
Slope		%
Fraction impervious		☐
3 Estimate design flow rates		
Time of concentration		
Estimate from flow path length and velocities		minutes ☐
Identify rainfall intensities		
Station used for IFD data		
100-year ARI		mm/hr
1-year ARI		mm/hr ☐
Design runoff coefficient		
C_{10}		
C_{100}		☐
Peak design flows		
Q_1		m^3/s
Q_{100}		m^3/s ☐
4 Sedimentation chamber		
Required surface area		m^2
Length:width ratio		
Length x width		m
Permanent pool depth		m
Extended detention depth		m
CHECK SCOUR VELOCITY (depends on particle size)		<0.2 m/s ☐
5 Sand filter chamber		
Inlet weir length		m
Particle sizes		mm
Filter saturated hydraulic conductivity		mm/hr
Extended detention depth		m
Overflow weir capacity		m^3/s
CHECK OVERFLOW CAPACITY		
6 Slotted collection pipe capacity		
Pipe diameter		mm
Number of pipes		
Pipe capacity		m^3/s
Capacity of perforations		m^3/s
Soil media infiltration capacity		m^3/s
CHECK PIPE CAPACITY > SOIL CAPACITY		☐
7 Sand filter properties		
Particle size	% Passing	
		%
		%
		%
		%
		%
		%
		% ☐

7.4 Checking tools

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

Checklists are provided for:

- design assessments
- construction (during and post)

- operation and maintenance inspections
- asset transfer (following defects period).

7.4.1 Design assessment checklist

The *Sand Filter Design Assessment Checklist* presents the key design features that should be reviewed when assessing a design of a sand filter. 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 installations. 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.

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 7.4.4).

7.4.2 Construction advice

General advice is provided for the construction of sand filters. It is based on observations from construction projects around Australia.

Building phase damage

It is important to protect filtration media during the building phase as uncontrolled building site runoff is likely to cause excessive sedimentation, introduce debris and litter and could cause clogging of the sand media. Upstream measures should be employed to control the quality of building site runoff. If a sand filter is not protected during the building phase, it is likely to require replacement of the sand filter media. An additional system of installing a geotextile fabric over the surface of the sand filter during the building phase can also protect the sand filter media below. Accumulated sediment and the geotextile fabric can then be removed after most of the upstream building activity has finished.

Traffic and deliveries

Ensure traffic and deliveries do not access sand filters during construction. Traffic can compact the filter media and cause preferential flow paths, deliveries can block filtration media. Washdown wastes (e.g. concrete) can cause blockage of filtration media. Sand filters should be fenced off during the building phase and controls implemented to avoid washdown wastes.

Sediment basin drainage

When a sediment chamber is designed to drain between storms (so that pollutants are stored in a drained state) weep holes can be used that are protected from blockage. Blockage can be avoided by constructing a protective sleeve e.g. 5 mm screen (to protect the holes from debris blockage) around small holes at the base of the bypass weir. Sediment basin drainage can also be achieved with a vertical slotted PolyVinyl Chloride (PVC) pipe, with protection from impact and an inspection opening at the surface to check for sediment accumulation. The weep holes should be sized so that they only pass small flows (e.g. 10–15 mm diameter).

Perforated pipes

Perforated pipes can be either a PVC pipe with slots cut into its length or a flexible ribbed pipe with smaller holes distributed across its surface (an AG pipe). Both can be suitable. PVC pipes have the advantage of being stiffer with less surface roughness and therefore greater flow capacity; however, the slots are generally larger than for flexible pipes and this may cause problems with filter or drainage layer particle ingress into the pipe. Stiff PVC pipes, however, can be cleaned out easily using simple plumbing equipment. Flexible perforated pipes have the disadvantage of roughness (therefore lower flow capacity); however, they have smaller holes and are flexible which can make installation easier. Blockages within the flexible pipes can be harder to dislodge with standard plumbing tools.

Sand Filter Design Assessment Checklist					
Sand filter location:					
Hydraulics	Minor flood: (m^3/s)		Major flood: (m^3/s)		
Area	Catchment area (ha):		Sand filter area (m^2)		
Treatment				**Y**	**N**
Treatment performance verified from curves?					
Inlet zone/hydraulics				**Y**	**N**
Station selected for IFD appropriate for location?					
Sediment chamber dimensions sufficient to retain 125 µm particles?					
Drainage facilities for sediment chamber provided?					
Overall flow conveyance system sufficient for design flood event?					
Velocities at inlet and within sand filter will not cause scour?					
Bypass sufficient for conveyance of design flood event?					
Collection system				**Y**	**N**
Slotted pipe capacity > infiltration capacity of filter media (where appropriate) ?					
Maximum spacing of collection pipes <1.5 m?					
Drainage layer >150 mm?					
Transition layer provided to prevent clogging of drainage layer?					
Filter Basin				**Y**	**N**
Maximum ponding depth will not impact on public safety?					
Selected filter media hydraulic conductivity > 10x hydraulic conductivity of surrounding soil?					
Maintenance access provided to base of filter media (where reach to any part of a basin >6 m)?					
Protection from gross pollutants provided (for larger systems)?					
Sand media specification included in design?					

Inspection openings in perforated pipes

It is good design practice to have inspection openings at the end of the perforated pipes. The pipes should be brought to the surface (with solid pipes) and have a sealed capping. This allows inspection of sediment build-up when required and easy access for maintenance, such as flushing out of accumulated sediments. Sediment controls downstream should be used when flushing out sediments from the pipes to prevent sediments reaching downstream waterways.

Clean filter media

Ensure drainage media is washed prior to placement to remove fines and prevent premature clogging of the system.

7.4.3 Construction checklist

CONSTRUCTION INSPECTION CHECKLIST

Sand filters

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					14. Location and levels of pits as designed				
2. Traffic control measures					15. Safety protection provided				
3. Location same as plans					16. Pipe joints and connections as designed				
4. Site protection from existing flows					17. Concrete and reinforcement as designed				
Earthworks					18. Inlets appropriately installed				
5. Level bed					19. Pipe joints and connections as designed				
6. Side slopes are stable					20. Concrete and reinforcement as designed				
7. Provision of liner					21. Inlets appropriately installed				
8. Perforated pipe installed as designed					**Filtration system**				
9. Drainage layer media as designed					22. Provision of liner				
10. Sand media specifications checked					23. Adequate maintenance access				
Sedimentation chamber					24. Inlet and outlet as designed				
11. Adequate maintenance access									
12. Invert level correct									
13. Ability to freely drain (weep holes)									

FINAL INSPECTION									
1. Confirm levels of inlets and outlets					6. Check for uneven settling of sand				
2. Traffic control in place					7. No surface clogging				
3. Confirm structural element sizes					8. Maintenance access provided				
4. Sand filter media as specified					9. Construction generated sediment and debris removed				
5. Sedimentation chamber freely drains									

COMMENTS ON INSPECTION

ACTIONS REQUIRED

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

7.4.4 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?		

7.5 Maintenance requirements

Maintenance of sand filters is primarily concerned with:

- regular inspections (every three to six months) to check the sedimentation chamber and the sand media surface
- flows to and through the sand filter
- removal of accumulated sediments and litter and debris from the sedimentation chamber
- ensuring the weep holes and overflow weirs are not blocked with debris.

Maintaining the flow through a sand filter involves regular inspection and removal of the top layer of accumulated sediment. Inspections should be conducted after the first few significant rainfall events following installation and then at least every six months following. The inspections will help to determine the long-term cleaning frequency for the sedimentation chamber and the surface of the sand media.

Removing fine sediment from the surface of the sand media can typically be performed with a flat-bottomed shovel or vacuum machinery. Tilling below this surface layer can also maintain infiltration rates. Access is required to the complete surface area of the sand filter and this needs to be considered during design.

Sediment accumulation in the sedimentation chamber also needs to be monitored. Depending on the catchment activities (e.g. building phase) the deposition of sediment can overwhelm the sedimentation chamber and reduce flow capacities.

Similar to other types of practices, debris removal is an ongoing maintenance function. Debris, if not removed, can block inlets or outlets, and can be unsightly Inspection and removal

Sand Filter Maintenance Checklist					
Inspection frequency:	6 monthly	Date of visit:			
Location:					
Description:					
Site visit by:					
Inspection items		Y	N	Action required (details)	
Litter within filter?					
Scour present within sediment chamber or filter?					
Traffic damage present?					
Evidence of dumping (e.g. building waste)?					
Clogging of drainage weep holes or outlet?					
Evidence of ponding?					
Damage/vandalism to structures present?					
Surface clogging visible?					
Drainage system inspected?					
Removal of fine sediment required?					
Comments:					

of debris should be done regularly, but debris should be removed whenever it is observed on the site.

7.5.1 Operation and maintenance inspection form

The *Sand Filter Maintenance Checklist* is designed to be used whenever an inspection is conducted and kept as a record on the asset condition and quantity of removed pollutants over time.

7.6 Sand filter worked example

7.6.1 Worked example introduction

A sand filter system is proposed to treat stormwater runoff from a courtyard/plaza area in Melbourne. The site is nested among several tall buildings and is to be fully paved as a multi-purpose courtyard. Stormwater runoff from the surrounding building is to be directed to bioretention planter boxes while runoff from this 5000 m^2 courtyard will be directed into an underground sand filter as determined by surface levels. Provision for overflow into the underground drainage infrastructure ensures that the site is not subjected to flood ponding for storm events up to the 100-year average recurrence interval. The existing stormwater drainage infrastructure has the capacity to accommodate the 100-year ARI peak discharge from this relatively small catchment.

Key functions of a sand filter include the following:

- promote the capture of gross pollutants
- promote sedimentation of particles larger than 125 μm within the **inlet zone** for flows up to a one-year ARI (unattenuated) peak discharge
- promote filtration of stormwater following sedimentation pretreatment through a sand layer
- provide for bypass operation by configuring and designing the bypass chamber.

The concept design suggests that the required area of the sand filter chamber is 40 m^2 and the depth of the sand filter is 600 mm. Outflows from the sand filter are conveyed into a stormwater pipe for discharge into existing stormwater infrastructure (legal point of discharge) via a third chamber, an overflow chamber. Flows in excess of a 200 mm extended detention depth would overflow and discharge directly into the underground stormwater pipe and bypass the sand filter.

7.6.1.1 Design objectives

The design objectives of a sand filter include:

- three chambers: a sedimentation (and **gross pollutant trapping**, **GPT**) chamber, a sand filter chamber and an overflow chamber
- capture of particles larger than 125 µm for flows up to the peak one-year ARI design flow with a capture efficiency of 80% – the chamber outlet will need to be configured to direct flows up to the one-year ARI into the sand filter, wheras flows in excess of the one-year ARI will bypass to the overflow chamber
- filtration of the peak one-year ARI flow – perforated subsoil drainage pipes are to be provided at the base of the sand filter and will need to be sized to ensure the flow can enter the pipes (check inlet capacity) and to ensure they have adequate flow capacity
- an overflow chamber designed to capture and convey flows in excess of the one-year ARI peak flow and up to the 100-year ARI peak discharge
- a sedimentation chamber to retain sediment and gross pollutants in a dry state and to have sufficient storage capacity to limit sediment clean-out frequency to once per year
- inlet/outlet pipes to be sized to convey the 100-year ARI peak discharge.

7.6.1.2 Site characteristics

The site characteristics are:

- catchment area of 5000 m^2 (100 m × 50 m)
- Paved courtyard land use/surface type
- a 1.0% overland flow slope
- soil is clay
- fraction impervious is 0.90.

7.6.2 Verifying size for treatment

The nominated area of the sand filter is 40 m^2.

A sand filter area of approximately 1% of the impervious area with a hydraulic conductivity of 360 mm/hr will be necessary to attain best practice objectives.

With a fraction impervious of 0.80, the impervious area of the courtyard is 4000 m^2 and the required sand filter area is 40.0 m^2 → OK

Sand filter area provided is adequate.

7.6.3 Estimating design flows

Length of the longest flow path is assumed to consist of an overland flow path ($\frac{1}{2}$ width of the courtyard is 25 m) and gutter flow ($\frac{1}{2}$ perimeter length of the courtyard is 150 m).

The travel time of the overland flow path can be estimated using the overland kinematic wave equation (Equation 7.4) presented in Australian Rainfall and Runoff (Institution of Engineers 2001, Book VIII), i.e.

$$t = \frac{6.94(L \times n^*)^{0.6}}{I^{0.4} \times S^{0.3}} \qquad \text{(Equation 7.4)}$$

where: t is the is the overland travel time (minutes); L is the overland flow path length (m); n^* is the surface roughness (concrete or asphalt ~0.013); I is the design rainfall intensity (mm/hr); and S is the slope.

An iterative application of Equation 7.4 will be required since the travel time will define the time of concentration of the catchment which in turn defines the appropriate design rainfall intensity.

Assuming a time of concentration (t_c) of six minutes: $I^{1}_{6\text{min}}$ = 44 mm/hr; $I^{100}_{6\text{min}}$ = 170 mm/hr.

From Equation 7.4, the overland flow travel times for the one-year and 100-year storms are calculated to be 3 min and 2 min, respectively. Gutter flow travel time, estimated from an assumed flow velocity of 1 m/s, is 2 min–3 min, giving an estimate total travel time of between 4 min and 6 min → OK to adopt a 6 min time of concentration.

Design rainfall intensities are I_1 = 44 mm/hr; I_{100} = 170 mm/hr.

Design runoff coefficients are computed using the method outlined in *Australian Rainfall and Runoff* (Institution of Engineers 2001, Book VIII).

$^{10}I_1$ = 28.6 mm/hr; f = 0.80

C^1_{10} = 0.1 + 0.0133 ($^{10}I_1$ –25) = 0.15, where C^1_{10} is the pervious runoff coefficient

$C_{10} = 0.9f + C^1_{10}$ (1 [–] f), where f is the fraction impervious, 0.8.

C_{10} = 0.75.

From Table 1.6 in Institution of Engineers 2001 Book VII;

$C_1 = 0.8 \times C_{10} = 0.60$

$C_{100} = 1.2 \times C_{10} = 0.90$.

Peak design flows (Q) are calculated using the Rational Method as follows:

$$Q = \frac{CIA}{360}$$

where C is the runoff coefficient; I is the design rainfall intensity (mm/hr); A is the catchment area (ha).

Q_1 = 0.037 m^3/s.

Q_{100} = 0.21 m^3/s.

7.6.3.1 Maximum infiltration rate

The maximum infiltration rate (Q_{max}) through the sand filter is computed using Equation 7.1 (Darcy's equation):

$$Q_{max} = k \times A \times \frac{h_{max} + d}{d} = 0.05 \text{ m}^3/\text{s}$$

where k is the hydraulic conductivity of sand = 1×10^{-4} m/s (Engineers Australia 2003, Ch. 9); A is the surface area of the sand filter, 40 m^2; h_{max} is the depth of pondage above the sand filter = 0.2 m; d is the depth of the sand filter = 0.6 m.

Design flows Q_1 = 0.004 m^3/s; Q_{100} = 0.21 m^3/s;
Maximum infiltration rate = 0.005 m^3/s.

7.6.4 Hydraulic structures

7.6.4.1 Sizing of sedimentation basin

The sedimentation chamber is to be sized to remove the 125 µm particles for the peak one-year flow.

Pollutant removal is estimated using Equation 4.3 (see Chapter 4):

$$R = 1 - \left[1 + \frac{1}{n} \times \frac{v_s}{Q/A} \times \frac{(d_e + d_p)}{(d_e + d^*)}\right]^{-n}$$

A notional aspect ratio of 1 (W) to 2 (L) is adopted. From Figure 4.3, the hydraulic efficiency (λ) is 0.3. The turbulence factor (***n***) is computed from Equation 4.2 to be 1.4.

Hydraulic efficiency (λ) = 0.3
Turbulence factor (**n**) = 1.4.

The proposed extended detention depth of the basin is 50 mm (0.05 m) (see Section 7.6.1) and a notional **permanent pool** depth of 0.95 m (equal to the depth of the sand filter) has been adopted:

d_p = 0.95 m

d^* = 0.95 m

d_e = 0.05 m

V_s = 0.011 m/s for 125 µm particles

Q = design flow rate = 0.37 m^3/s.

The required sedimentation basin area to achieve target sediment (125 μm) capture efficiency of 70% is 7 m^2. With a W to L ratio of 1:2, the notional dimensions of the basin are 2 m × 3.5 m. This size is validated against the curves presented in Figure 4.2 (see Chapter 4).

The available sediment storage is 7 × 0.95 = 6.7 m^3. Clean-out is to be scheduled when the storage is half full. Using a sediment discharge rate of 1.6 m^3/ha per year, the clean-out frequency is estimated to be:

$$\text{Frequency of basin desilting} = \frac{0.5 \times 6.7}{0.7 \times 1.6 \times 0.5} \text{ years} > 1 \text{ year} \rightarrow \text{OK}$$

During the 100-year ARI storm, peak discharge through the sedimentation chamber will be 0.21 m^3/s with flow depth of 0.95 m. It is necessary to check that flow velocity does not resuspend deposited sediment of 125 μm or larger (≤ 0.2 m/s).

The mean velocity in the chamber is calculated as follows:

$$V_{100} = 0.21/(2 \times 0.95) = 0.11 \text{ m/s} \rightarrow \text{OK}$$

The length of the sedimentation chamber is 3.5 m. Provide 0.2 m high slots of total length of 2 m connecting it to the sand filter chamber. The connection discharge capacity ($Q_{connection}$) should be greater than the 100-year ARI peak flow (0.21 m^3/s) and can be calculated using the broad-crested weir equation (Equation 7.2) as follows:

$$Q_{connection} = C_w L H^{1.5}$$

where: C_w is the weir coefficient (assume = 1.4 for a broad-crested weir); H is the afflux = 0.2 m (2 m) weir; L is the length of the weir.

The discharge capacity calculated from the above equation is 0.25 m^3/s >> 100-year ARI discharge of 0.21 m^3/s.

Sedimentation chamber = 7 m^2
Width = 2 m; Length = 3.5 m
Total weir length of connection to sand filter chamber = 2 m
Depth of chamber from weir connection to sand filter = 0.6 m
Depth of Extended Detention (d_e) = 0.05 m.

7.6.4.2 Sand filter chamber

Dimensions

With the length of sedimentation chamber being 3.5 m, the dimension of the sand filter chamber is determined to be 3.5 m × 11.5 m, giving an area of 40.25 m^2.

Sand filter chamber dimension: 3.5 m × 11.5 m.

Media specifications

Sand filter layer to consist of sand material with a typical particle size distribution (based on a Unimin 16/30 FG sand grading) is provided:

Percentage passing	1.4 mm	100%
	1.0 mm	80%
	3.17 mm	44%
	1.5 mm	8.4%

The drainage layer is to consist of fine gravel, of 5 mm screenings.

No impervious liner is necessary as *in situ* soil is clay.

The filter layer is to be 600 mm deep and consist of sand with approximately 50% finer than 1 mm diameter. The drainage layer to be 200 mm deep and consist of 5 mm gravel.

7.6.4.3 Overflow chamber

A weir set at 0.95 m from the base of the sedimentation chamber (or 0.2 m above the surface of the sand filter) of 2 m length needs to convey flows up to the 100-year ARI peak discharging from the sand filter chamber into the overflow chamber.

To calculate the afflux resulting from conveying the 100-year ARI peak discharge through a 2 m length weir, perform the following:

$$H = \left(\frac{Q_{\text{wer}}}{C_{\text{w}} \times L}\right)^{0.667} = 0.16 \text{ m, say } 0.2 \text{ m} \qquad \text{(Equation 7.5)}$$

where: Q_{weir} is the design discharge = 0.21 m^3/s
C_w is the weir coefficient (~1.7)
L is the length of the weir (m)
H is the afflux (m).

With an afflux of 0.2 m, the discharge capacity of the overflow weir is 0.30 m^3/s > 100-year ARI peak flow of 0.23 m^3/s.

Crest of overflow weir = 0.2 m above surface of sand filter
Length of overflow weir = 2 m
100-year ARI afflux = 0.2 m
Roof of facility to be at least 0.4 m above sand filter surface.

7.6.5 Size of slotted collection pipes

7.6.5.1 Perforations inflow check

The following are the characteristics of the selected slotted pipe:

- clear openings = 2100 mm^2/m
- slot width = 1.5 mm
- slot length = 7.5 mm
- No. rows = 6
- Diameter of pipe = 100 mm.

For a pipe length of 3.5 m, the total number of slots = 2100/(1.5 × 7.5) = 186.

Discharge capacity of each slot can be calculated using the orifice flow equation (Equation 7.3), i.e.

$$Q_{perforation} = C \times A_{perforation}\sqrt{2gh} = 2.67 \times 10^{-5} \text{ m}^3/\text{s}$$

where: h is the head above the slotted pipe, calculated to be 0.80 m; C is the orifice coefficient (about 0.6). The inflow capacity of the slotted pipe is thus
$2.67 \times 10^{-5} \times 186 = 5 \times 10^{-3}$ m^3/s per metre of length.

If a blockage factor of 0.5 is adopted, this gives the inlet capacity of each slotted pipe to be 2.5×10^{-3} m^3/s per metre of length.

Maximum infiltration rate is 0.005 m^3/s. Therefore, the minimum length of slotted pipe ($L_{\text{slotted pipe}}$) required is:

$$L_{\text{slotted pipe}} = 0.005/2.5 \times 10^{-3} = 2 \text{ m}$$

The minimum recommended pipe spacing is 1.5 m (refer Section 7.3.3), therefore, six slotted pipes (3.5 m length) at 1.5 m spacing are required.

7.6.5.2 Slotted pipe capacity

The diameter of the slotted pipe is 100 mm. The discharge capacity of the collection pipe is calculated using an orifice flow equation (Equation 7.3):

$$Q_{\text{pipe}} = C \times A_{\text{pipe}}\sqrt{2gh} = 0.019 \text{ m}^3/\text{s} \qquad \text{(Equation 7.6)}$$

Total discharge capacity (six pipes) = 0.11 m^3/s > maximum infiltration rate of 0.005 m^3/s → OK

Combined slotted pipe discharge capacity = 0.11 m^3/s
and this exceeds the maximum infiltration rate.

7.6.6 Design calculation summary

The completed *Sand Filters Calculation Checksheet* shows the results of the design calculations.

Sand Filters	CALCULATION SUMMARY		
CALCULATION TASK	OUTCOME		CHECK
1 Identify design criteria			
Conveyance flow standard (ARI)	100	year	
Treatment flow rate (ARI)	1	year	
Pretreatment objective	125	μm	
Sand filter area	10	m^2	
Sand filter depth	0.6	m	
Maximum ponding depth	200	mm	✓
2 Catchment characteristics			
Area	5000	m^2	
Slope	1	%	
Fraction impervious	0.9		✓
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	Melbourne		
100-year ARI	170	mm/hr	
1-year ARI	44	mm/hr	✓
Design runoff coefficient			
C_{10}	0.82		
C_{100}	0.99		✓
Peak design flows			
Q_1	0.04	m^3/s	
Q_{100}	0.24	m^3/s	✓
4 Sedimentation chamber			
Required surface area	7	m^2	
Length:width ratio	1(W):2(L)		
Length x width	2 x 3.5	m	
Permanent pool depth	0.95	m	
Extended detention depth	0.05		
CHECK SCOUR VELOCITY (depends on particle size)	0.11	<0.2 m/s	✓
5 Sand filter chamber			
Inlet weir length	2	m	
Particle sizes	0.7	mm	
Filter saturated hydraulic conductivity	360.0	mm/hr	
Extended detention depth	0.2	m^3/s	
Overflow weir capacity	0.3	m^3/s	
CHECK OVERFLOW CAPACITY	YES		✓
6 Slotted collection pipe capacity			
Pipe diameter	100	mm	
Number of pipes	6		
Pipe capacity	0.11	m^3/s	
Capacity of perforations	0.05	m^3/s	
Soil media infiltration capacity	0.005	m^3/s	
CHECK PIPE CAPACITY > SOIL CAPACITY	YES		✓
7 Sand filter properties			
Percent Passing 1.40	100	%	
Unimin 16/30 FG 1.18	96	%	
1.00	80	%	
0.85	63	%	
0.71	44	%	
0.60	24	%	
0.50	8	%	
0.425	1	%	✓

7.6.7 Construction drawings

The following page shows the construction drawing for the worked example.

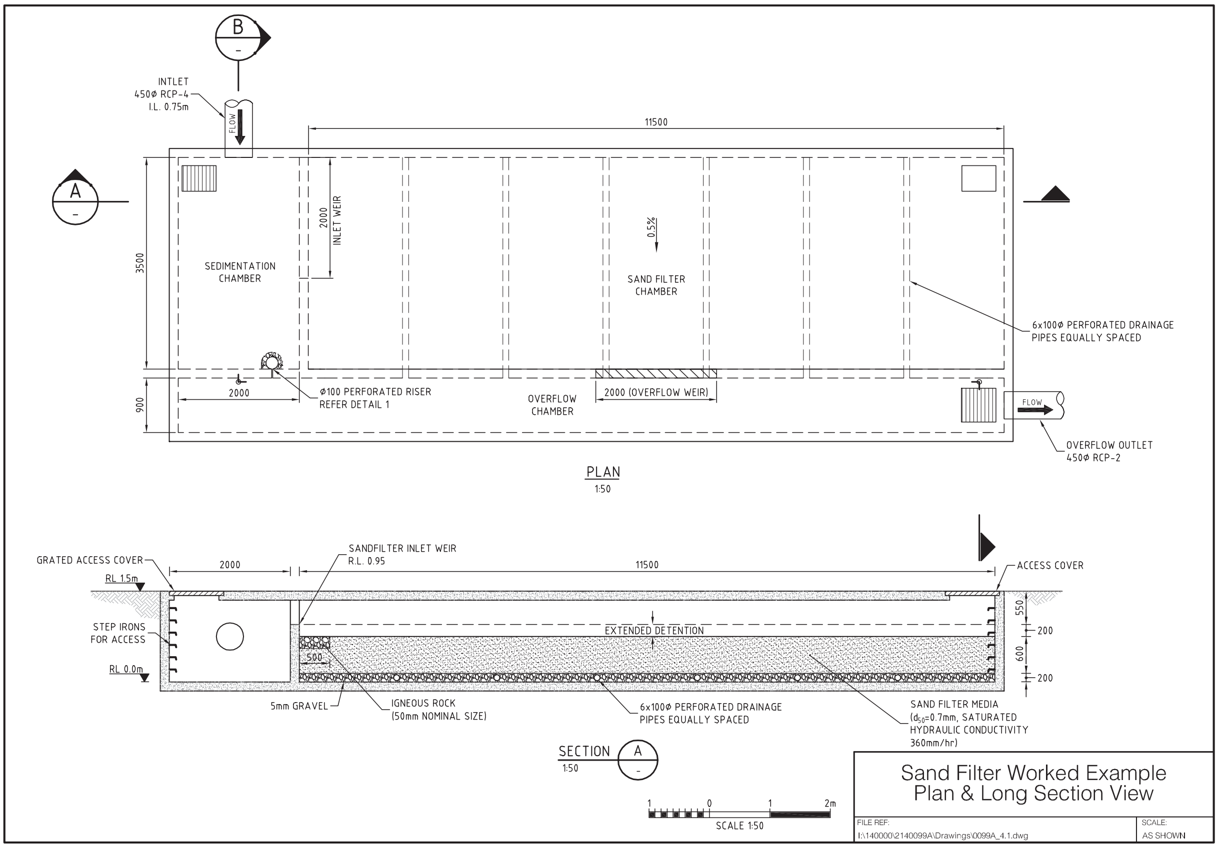


Figure 7.8 Plan and long section view

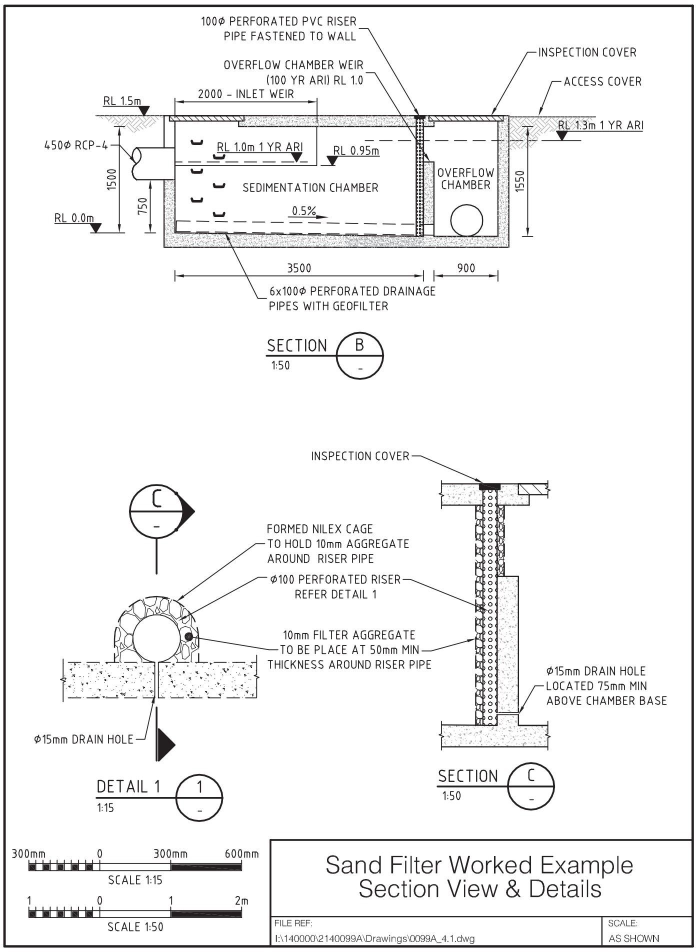


Figure 7.9 Section view and details

7.7 References

Auckland Regional Council (ARC) (2003). *Stormwater Management Devices: Design Guidelines Manual* (TP10), 2nd edn, Auckland Regional Council, Auckland.

Cooperative Research Centre for Catchment Hydrology (CRCCH) (2003). *Model for Urban Stormwater Improvement Conceptualisation (MUSIC) User Guide*, Version 2.0, CRCCH, Monash University, Victoria.

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

Institution of Engineers Australia (1997). *Australian Rainfall and Runoff – A Guide to Flood Estimation*, Pilgram, D.H. (Ed.), Institution of Engineers, Australia, Barton, ACT.