Policy 11: Land Development Guidelines

Section 13 Water Sensitive Urban Design (WSUD) Guidelines

13.9 Sand Filters

Sand Filters for Detention and Filtration of Stormwater Runoff

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13.9.1 Introduction

Sand filters operate in a similar manner to bioretention systems, with the exception that stormwater passes through a filter media (typically sand) that has no vegetation growing on the surface. Sand filters do not incorporate vegetation because the filter media does not retain sufficient moisture to support plant growth and they are often installed underground (therefore light limits plant growth). The absence of vegetation and the associated biologically active soil layer typically created around the root zone of vegetation planted in bioretention systems, means sand filters have a reduced stormwater treatment performance compared to bioretention systems.

Sand filters should only be considered where site conditions, such as space or drainage grades, limit the use of bioretention systems. This is most likely related to retrofit situations where the surrounding urban environment is already developed. Treatment can then be achieved underground with sand filters, in areas such as high density developments with little or no landscape areas. Their lack of vegetation requires more regular maintenance than bioretention systems to ensure the surface of the sand filter media remains porous and does not become clogged with accumulated sediments. This typically involves regular inspections and routine removal of fine sediments that have formed a ‘crust’ on the sand filter surface.

Prior to entering a sand filter, flows must be subjected to pretreatment to remove litter, debris and coarse sediments (typically via an ‘inlet chamber’, which is designed as part of the system). Following pretreatment, flows are spread over the sand filtration media and water percolates downwards and is intercepted by perforated pipes located at the base of the sand media. The perforated pipes collect treated water for conveyance downstream. During higher flows, water can pond on the surface of the sand filter increasing the volume of water that can be treated. Very high flows are diverted around sand filters to protect the sand media from scour.

Key functions of a sand filter include the following:

- pretreatment to remove gross pollutants (where an inlet chamber is incorporated into the system);
- sedimentation of particles larger than 125 µm within a sedimentation chamber for flows up to a 1 year ARI (unattenuated) peak discharge;
- filtration of stormwater following sedimentation pretreatment through a sand filtration layer.

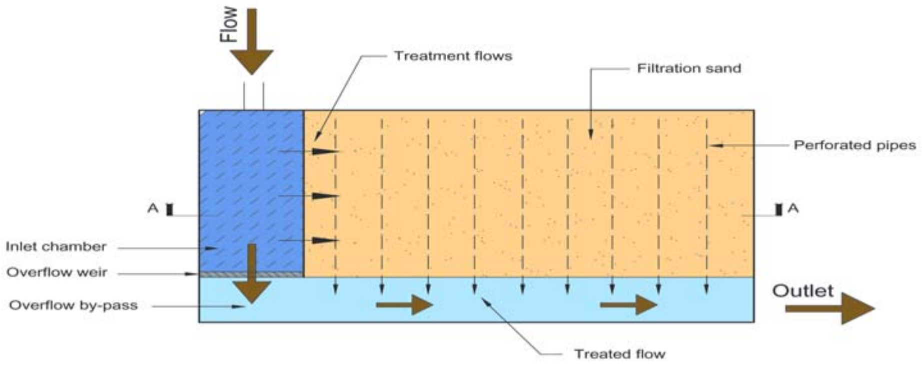
13.9.2 Design Considerations

13.9.2.1 Configuration

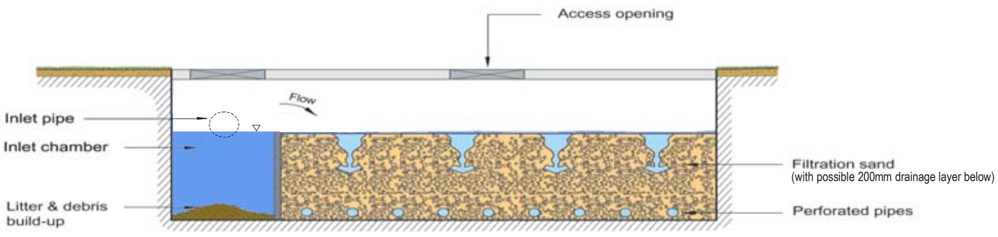
A sand filter system typically consists of three chambers: an inlet chamber that allows sedimentation and removal of gross pollutants, a sand filter chamber and a high flow bypass chamber, as illustrated in **Figure 13.9-A**. The shape of a sand filter can be varied to suit site constraints and maintenance access, provided each of the chambers is adequately sized.

a) Sedimentation Chamber

Water firstly enters the sedimentation (inlet) chamber where gross pollutants and coarse to medium-sized sediments 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 either have permanent water between events or to drain between storm events with weep holes. There are advantages and disadvantages with each approach. The decision of which type of system is most appropriate must be made based on catchment runoff characteristics and downstream receiving environment, likely maintenance programs (and available equipment) and site accessibility.



Plan



Section A - A (during operation)

Figure 13.9-A: Typical Sand Filter Configuration During Operation

Having a permanent water body reduces the likelihood of resuspension of sediments at the start of subsequent rainfall events as inflows do not fall and scour collected sediments. This system requires the removal of wet material from the sedimentation chamber during maintenance, which is more costly than for drained material. However, where appropriate maintenance machinery (such as vacuum trucks) is available, these costs may be manageable. A potential issue with these systems arises from the stagnant water and potentially high organic loads that can lead to anaerobic conditions. This may cause the release of soluble pollutants (such as phosphorus). Release of these bioavailable pollutants can cause water quality problems downstream (such as excessive algal growth). Where the system lies upstream from another treatment measure (such as constructed wetland), the release of these bioavailable pollutants may be less of an issue.

Allowing the sedimentation chamber to drain during inter-event periods (by the installation of weep holes) reduces the likelihood of pollutant transformation during the inter-event period. The challenge with this system is to design weep holes such that they do not block and can continue to drain as material (litter, organic material and sediment) accumulates. Drained sediment chambers are also prone to resuspension of accumulated material as the initial flows from subsequent rainfall events enter the chamber. The chamber requires sufficient access space for manual removal of sediment and accumulated debris during maintenance operations. These factors need to be considered when designing the sedimentation chamber.

b) Sand Filter Chamber

Stormwater flows from the sedimentation chamber into the sand filter chamber via a weir. Water then percolates through the sand filtration media (typically 400-600 mm depth) and perforated under-drain pipes collect filtered water in a similar manner to bioretention systems. Provision for temporary ponding is provided within the sand filter chamber. When water levels reach the maximum ponding depth, flows spill over to an overflow (bypass) chamber (usually via the sedimentation chamber). The bypass chamber protects the sand media from scour during high flow events. The high saturated hydraulic conductivity of the sand filtration media means that only a small (~200 mm) extended detention (temporary ponding) depth is required.

The sand filtration media has an hydraulic conductivity ranging from 1 x 10-4 m/s (360 mm/hr) to 1 x 10-3 m/s (3600 mm/hr) depending on the sand particle size. The material should be free of fines and have a relatively uniform grain size distribution. Example particle size distributions are provided in **Section 13.9.3.4**.

The filter media consists of two layers, a drainage layer consisting of gravel material to encase the perforated under-drains 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 minimises potential scouring of the sand surface as water flows into the sand filter chamber. Alternatively, where the crest of the sediment chamber weir (treatment flow weir) is elevated above the sand filter surface, appropriate scour protection must be used.

The drainage layer contains either socked flexible perforated pipes (eg. ag pipes) or socked slotted PVC pipes, however care needs to be taken to ensure the slots in the pipes are not so large that particles can 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 downstream. They should be sized so that the filtration media freely drains and the collection system does not become a 'choke' in the system. There are 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 and therefore allow for increased biological treatment from longer contact time. 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.

c) Overflow Chamber

The overflow chamber provides a bypass during flood events to downstream drainage infrastructure. When water levels in the sedimentation and sand filter chambers exceed the extended detention depth, water overflows the weir into the bypass chamber and is conveyed into the downstream drainage system. The overflow weir is sized to ensure that it has sufficient capacity for the design discharge from the sedimentation chamber, typically the 2-10 year ARI **Figure 13.9-B** shows the inside of a sand filter in Auckland.

Figure 13.9-B: Underground Sand Filter (with overflow chamber in corner) for a Car Park in Auckland, New Zealand

13.9.2.2 Maintenance

Sand filters have no vegetation to break up the filter surface (unlike bioretention systems); therefore, maintenance is critical to ensuring continued performance, particularly in preserving the hydraulic conductivity of the filtration media. Without regular maintenance (eg. 3-6 months with more frequent inspections to determine clean out requirements), collected fine material will create a 'crust' on the surface that significantly decreases infiltration capacity. Regular maintenance involves removing the surface layer of fine sediments that can tend to clog the filtration media.

Inspections of the sedimentation chamber need to be performed every 1-6 months (as for the sand filter chamber), however, sediment and/or gross pollutant cleanout may only be required annually. The frequency will ultimately depend on upstream catchment activities and will be linked to seasonal rainfall (ie. high summer rainfall may require more frequent cleanouts). Of particular importance are regular inspections during and immediately following construction and these should be conducted after the first few significant rainfall events. Records of all inspections and maintenance activities should be documented and filed for future use.

There are several key decisions during design that significantly impact on ease of maintenance for a sand filter. Easy access for maintenance is fundamental to long term performance and needs to be considered early during design. This includes both access to the site (eg. traffic management options) as well as access to the sedimentation and sand filter chambers (including less frequent access to the overflow chamber).

Direct physical access to the whole surface of the sand filter chamber will be required to remove fine sediments from the surface layer of the filter media (top 25-50 mm) as they accumulate forming a crust. Depending on the scale of the system, this may require multiple entry points to the chamber to enable access with a shovel or vacuum machinery. If maintenance crews cannot access part of the sand filter chamber, it will quickly become blocked and thus reduce water quality improvement.

The sedimentation chamber needs to be drained for maintenance purposes (unless appropriate wet extraction equipment is available). A drainage valve or gate should be incorporated into systems that have no weep holes so that this chamber can fully drain. Having freely drained material significantly reduces the removal and disposal maintenance costs. Alternatively, water in the sediment chamber can be pumped into the sand filter and then pollutants removed.

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 by extending the under-drains to the surface of the sand filter to allow for inspection and maintenance when required. The vertical section of the under-drain should be either solid pipe or wrapped in impermeable geotextile and a cap placed on the end of the pipe to avoid short circuiting of flows directly in to the drain. A temporary filter sock or equivalent should also be placed over the outlet pipe in the overflow chamber to capture flushed sediment during maintenance activities.

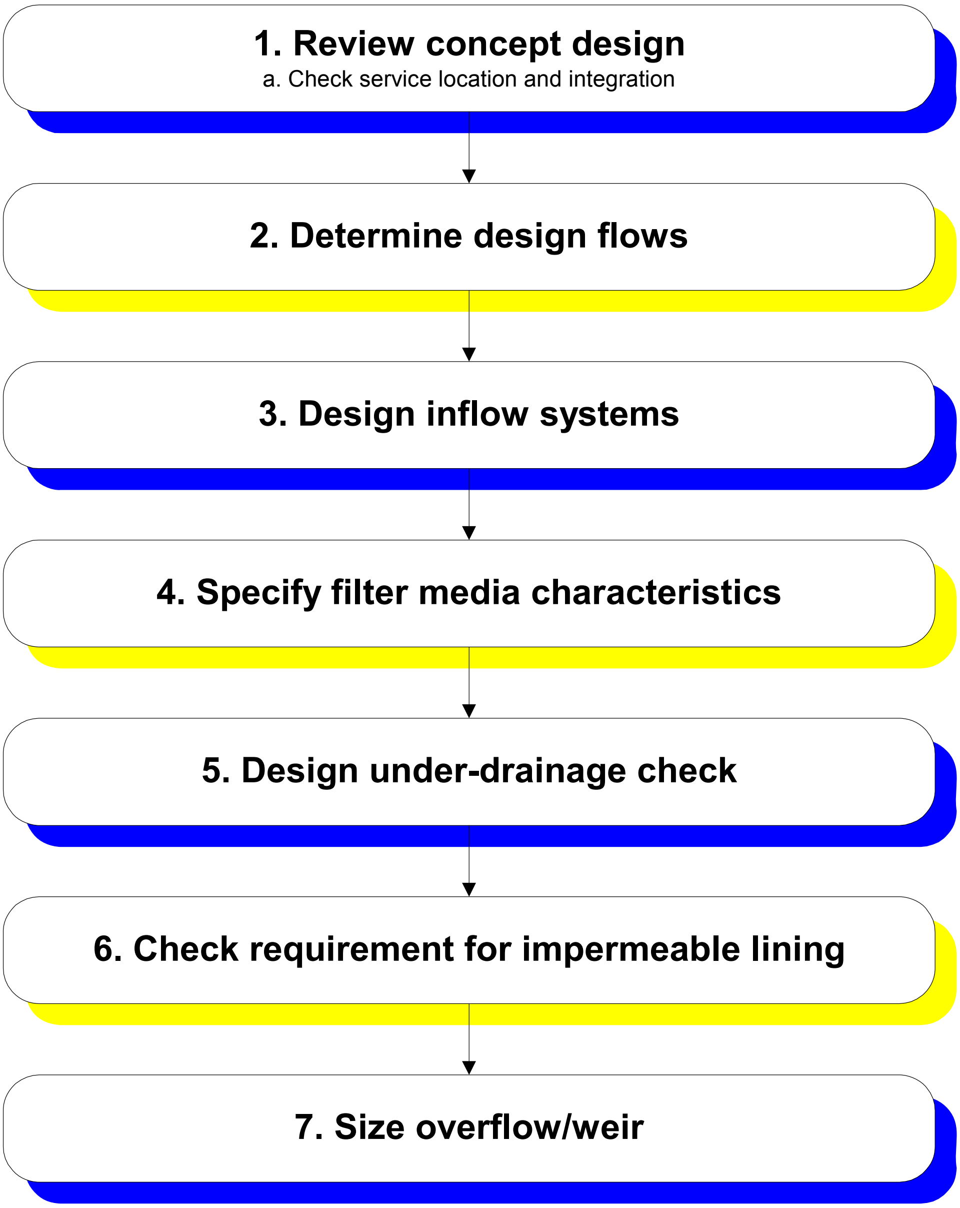
The location and signing should also give due consideration to the location on proposed location of existing and future services. Location of the sand filter should avoid:

- underground services including telecommunications and electricity;
- areas where existing or future water and sewerage services are required.

The location of WSUD devised should also avoid hindering access to these services for maintenance.

13.9.3 Design Process

The following sections detail the design steps required for sand filters. Key design steps are:



13.9.3.1 Step 1: Review Concept Design

Prior to progressing with detailed design, the designer should review the concept design developed for the site. The concept design should be reviewed to ensure:

- the sand filter, as part of a treatment train, provides an appropriate level of water quality treatment demonstrated through **MUSIC** modelling;
- sand filters are still appropriate for use at the site and are appropriately located within a treatment train;
- there are no additional constraints to the location and/or sizing of the sand filter.

A **MUSIC** model of the surrounding catchment and 'treatment train' should be developed at the conceptual design stage, prior to undertaking detailed design, to provide an initial estimate of the swale dimensions required to achieve GCCC load-based water quality objectives.

It should be noted that sand filters should form part of the stormwater 'treatment train' as they may not achieve load-based objectives on their own. Therefore, other stormwater quality best management practices should be incorporated into the surrounding catchment to augment the stormwater treatment performance of any proposed sand filter system.

As part of the review of the concept design, the designer should also ensure the concept design has considered the location of existing services and potential location of services has been considered.

The designer should liaise with others responsible for civil design and GCCC officers to ensure:

- access for maintenance of existing services;
- no damage to existing services will occur;
- no conflicts arise between location of services and WSUD devices.

Where relevant, the detailed design of WSUD devices should show how/ where other services are or will be located.

13.9.3.2 Step 2: Determine Design Flows

Three design flows are required for sand filters:

1. Sedimentation chamber design flow – this would normally correspond to a 1 year ARI peak discharge as standard practice for sedimentation basins.
2. Sand filter design flow (or maximum infiltration rate) – 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 under-drains to allow the filter media to freely drain.
3. Overflow chamber design flow – this would normally correspond to the minor drainage system (typically 2-10 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.

a) Minor and Major Flood Estimation

QUDM identifies the Rational Method as the procedure most commonly used to estimate peak flows from small catchments in Queensland. As sand filters are only recommended for small catchments (eg. less than 10 hectares), the Rational Method is recognized as an appropriate method to use in the determination of peak design flows.

b) Maximum Infiltration Rate

The maximum infiltration rate represents the design flow for the under-drainage system (ie. the slotted pipes at the base of the filter media). The capacity of the under-drains 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:

$$Q_{max} = K_{sat} \cdot A \cdot \frac{h_{max} + d}{d}$$

Where:

K_{sat} = hydraulic conductivity of the soil filter (m/s)

A = surface area of the sand filter (m^2)

h_{max} = depth of pondage above the sand filter (m)

d = depth of filter media (m)

Equation 13.9.1

13.9.3.3 Step 3: Design Sedimentation Chamber

The inlet into the sand filter is via a weir from the sedimentation chamber. The dimensions of this chamber should be sized to retain sediments larger than 125 μm for the sedimentation chamber design flow (typically 1 year ARI peak flow) and to have adequate capacity to retain settled sediment (and gross pollutants) such that the cleanout frequency is a minimum of once per year (more frequent cleanouts are likely on the Gold Coast as per **Section 13.9.2.2**). A target sediment capture efficiency of 70% is recommended. This is lower than would be recommended for sedimentation basins that do not form part of a sand filter (see **Section 13.5**). 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 a 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 significant rainfall events and soon after the device has been constructed to ensure sediment and gross pollutant loads can be controlled in the sedimentation chamber.

Weep holes are also provided when a sedimentation chamber is designed to drain following storm events. During storm events, stormwater in the sedimentation chamber is discharged (via surcharge) over a weir into the sand filter chamber. This weir will have a maximum discharge capacity that is equal to the sand filter design flow.

It is necessary to check that deposited sediments of the target sediment size or larger are not resuspended during the passage of the design peak discharge for the overflow bypass channel. A maximum flow velocity of 0.2 m/s is recommended through the sedimentation chamber before bypass occurs and 0.5 m/s for the overflow design flow rate. Velocities are estimated by dividing the cross section area by the design flow rate.

The reader is referred to **Section 13.5** for guidance on sizing the sedimentation chamber allowing for the recommended 70% capture efficiency for sediments.

13.9.3.4 Step 4: Specify the Filter Media Characteristics

Filter media in the sand filter chamber consist of two layers:

1. A drainage layer consisting of gravel material to encase the perforated under-drains.
2. A sand filtration layer. The surface of the sand filter should preferably be set at the crest of the weir connecting the sedimentation chamber to the sand filter chamber (unless sufficient scour protection is used for elevated weirs). This minimises any scouring of the sand surface as water is conveyed into the filter chamber.

a) Filter Media

A range of particle sizes 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 being effective for stormwater treatment (**ARC 2003**):

% 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 m	2-10%

This grading is based on TP10 (**ARC 2003**).

Alternatively, finer material can be used (described below), however this will require more attention to maintenance to ensure the material maintains sufficient hydraulic conductivity and does not become blocked. Inspections should be carried out every 1-6 months during the initial year of operation as well as after major storms to check for surface clogging.

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

b) Drainage Layer

A drainage layer is used to convey treated flows from the base of the filter media layer into the perforated under-drainage system. The particle size of the drainage layer is selected with consideration of the perforated under-drainage system (refer to **Section 13.9.3.5**) as the slot sizes in the perforated pipes may determine the minimum drainage layer particle size that will not be washed into the perforated pipes. Coarser material (eg. fine gravel) must be used for the drainage layer if the slot sizes in the perforated pipes are too large for use of a sand based drainage layer. Otherwise, sand is the preferred drainage layer media as it is likely to avoid having to provide a transition layer (like in bioretention systems) between the filter media and the drainage layer. The drainage layer must be a minimum of 200 mm thick.

13.9.3.5 Step 5: Design Check Under-drainage

Treated water that has passed through the filtration media is directed into slotted pipes located within the 'drainage layer' or at the base of the sand filtration layer (when a drainage layer is not required). The maximum spacing of the slotted or perforated collection pipes is 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. Collection pipes are to be a maximum of 100 mm diameter. To ensure the slotted or perforated pipes are of adequate size, several checks are required:

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

a) Perforations Inflow Check

To estimate the capacity of flows through the perforations, orifice flow conditions are assumed and a sharp edged orifice equation can be used. Firstly, 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. Secondly, it is conservative but reasonable to use a blockage factor (eg. 50% blocked) to account for partial blockage of the perforations by the drainage layer media.

$$Q_{perf} = B \cdot C_d \cdot A_{perf} \cdot \sqrt{2 \cdot g \cdot h}$$

Where:

Q_{perf} = flow through perforations (m^3/s)
B = blockage factor (0.5 – 0.75)
C_d = orifice discharge coefficient (~0.6)
A = total area of perforations (m^2)
g = gravity (9.81 m/s^2)
h = depth of water over the collection pipe (m)

Equation 13.9.2

The combined discharge capacity of the perforations in the collection pipe(s) must 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.

b) Perforated Pipe Capacity

The discharge capacity of the collection pipe (Q_{pipe}) can be calculated using an orifice flow equation similar to that expressed in **Equation 8.2**, assuming that the pipe has no blockage restricting the flow (ie. B = 1). This equation is used in preference to Manning's equation, as the pipe is completely submerged while discharging:

$$Q_{pipe} = C_d \cdot A_{pipe} \sqrt{2 \cdot g \cdot h}$$

Where:

Q_{pipe} = flow through pipe(s) (m^3/s)
C_d = orifice discharge coefficient (~0.6)
A = area of the pipe(s) (m^2)
g = gravity (9.81 m/s^2)
h = depth of water over the collection pipe (m)

Equation 13.9.3

The capacity of this pipe must exceed the maximum infiltration rate.

13.9.3.6 Step 6: Check Requirements for Impermeable Lining

Sand filters are considered as conveyance filtration devices not infiltration systems. Stormwater is treated via filtration through a specified soil media with the filtrate collected in a sub-surface drainage system to be either discharged as treated surface flow or collected for reuse. The amount of water lost to surrounding soils is highly dependent on local conditions and the hydraulic conductivity of the filtration media in the sand filter. Where sand filters are installed adjacent to significant structures, care should be taken to minimise any leakage from the sand filter. Soil tests of the surrounding soils should be undertaken, including tests on the typical hydraulic conductivity.

Should surrounding soils be very sensitive to seepage from sand filters (eg. 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 (10 times) of the filtration media. If this is the case, an impervious liner must be used to contain all water within the sand filter. The liner should be a flexible membrane or a concrete casing. A leakage test must be done immediately after construction to ensure that leakage from the filter does not occur.

13.9.3.7 Step 7: Size Overflow Weir

The overflow weir is typically located in the sedimentation chamber. The overflow weir must be sized to ensure that it has sufficient capacity to convey the design discharge from the sedimentation chamber (typically 2-10 year ARI peak flow).

When water levels in the sedimentation and sand filter chambers exceed the extended detention depth, water will overflow directly from the sedimentation chamber (bypassing the sand filter) into the overflow/ bypass chamber and be conveyed into the downstream drainage system. Water levels in the overflow chamber must 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:

$$Q_{weir} = C_w \cdot L \cdot h^{3/2}$$

Where:

Q_{weir} = flow rate over weir (m^3/s)

C_w = weir coefficient (~1.7)

L = length of the weir (m)

h = depth of water above the weir (m)

Equation 13.9.4

13.9.3.8 Design Calculation Summary

Below is a design calculation summary sheet for key design elements of sand filters to aid the design process.

Sand Filter	Calculation Summary	
Calculation Task	**Outcome**	**Check**
Catchment Characteristics		
Catchment Area	Ha	
Catchment Land Use (ie. Residential, Commercial, etc)		
Storm Event Entering Inlet	yr ARI	
Conceptual Design		
Sand Filter Area	m^2	
Filter Media Saturated Hydraulic Conductivity	mm/hr	
Extended Detention Depth	mm	
1 Review Conceptual Design		
Conceptual Design Reviewed Using **MUSIC** Model		
Total Suspended Solids	%	
Total Phosphorus	%	
Total Nitrogen	%	
Sand filter area	m^2	
Extended detention depth	m	
2 Determine Design Flows		
Time of Concentration		
Refer to **GCCC Land Development Guidelines** and **QUDM**	minutes	
Identify Rainfall Intensities		
$I_{1\ \text{year ARI}}$	mm/hr	
$I_{2\ \text{year ARI}}$	mm/hr	
$I_{50\ \text{year ARI}}$	mm/hr	
Design Runoff Coefficient		
$C_{1\ \text{year ARI}}$		
$C_{2\ \text{year ARI}}$		
$C_{50\ \text{year ARI}}$		
Peak Design Flows		
1 year ARI	m^3/s	
2 year ARI	m^3/s	
50 year ARI	m^3/s	
$Q_{\text{infiltration}}$	m^3/s	
3 Design Sedimentation Chamber		
Required Surface Area?	m^2	
Length x Width	m	
Depth	m	
Design Particle Size	mm	
Check SCOUR VELOCITY (<0.5 m/s ?)	m/s	
Check OVERFLOW CAPACITY?	m^3/s	
4 Specify Sand Filter Media Characteristics		
Filter Media Hydraulic Conductivity	mm/hr	
Filter Media Depth	mm	
Drainage Layer Depth	mm	
Provided Specification for Sand Media?		
5 Design and Check Under-Drainage		
Flow Capacity of Filter Media	m^3/s	

Sand Filter	Calculation Summary	
Calculation Task	**Outcome**	**Check**
Perforations Inflow Check		
Pipe Diameter	mm	☐
Number of Pipes		
Capacity of Perforations	m^3/s	
Check PERFORATION CAPACITY > FILTER MEDIA CAPACITY		
Perforated Pipe Capacity		
Pipe Capacity	m^3/s	☐
Check PIPE CAPACITY > FILTER MEDIA CAPACITY		
6 Check Requirement for Impermeable Lining		
Soil Hydraulic Conductivity	mm/hr	☐
Filter Media Hydraulic Conductivity	mm/hr	
More than 10 TIMES HIGHER than *IN-SITU* SOILS?		
7 Size Overflow Weir		
Design Storm for Overflow (eg. 2yr ARI)		☐
Weir Length	m	

13.9.4 Construction Advice

This section provides general advice for the construction of sand filters. It is based on observations from construction projects around Australia.

13.9.4.1 Building Phase Damage

Protection of sand filtration media is very important during the building phase; 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 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 when the upstream building activity has finished.

13.9.4.2 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 provided. Blockage of the weep holes can be avoided by constructing a protective sleeve (to protect the holes from debris blockage, eg. 5 mm screen) around small holes at the base of the bypass weir. It can also be achieved with a vertical slotted 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 (eg. 10-15 mm diameter).

13.9.4.3 Perforated Pipes

Perforated pipes can be either a socked PVC pipe with slots cut into the length of it or a socked flexible ‘ribbed’ pipe with smaller holes distributed across its surface (eg. ag pipe). Both are suitable, although PVC pipes have the advantage of being stiffer with less surface roughness, and therefore have greater flow capacity than flexible ‘ribbed’ pipes. The slots in PVC pipes are generally larger than the holes in flexible ribbed pipe, so there is an increased risk of soil particle ingress into the pipe. Stiff PVC pipes can however be cleaned out easily using simple plumbing equipment, whereas blockages within flexible pipes can be harder to dislodge with standard plumbing tools.

13.9.4.4 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 accumulated sediments. Sediment controls downstream should be used when flushing out sediments from the pipes to prevent sediments reaching downstream waterways.

13.9.4.5 Clean Filter Media

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

13.9.5 Maintenance Requirements

Maintenance of sand filters is primarily concerned with:

- regular inspections (1-6 monthly) to inspect the sedimentation chamber and the sand media surface, particularly immediately after construction;
- maintenance of flows to and through the sand filter (ie. checking for blockage);
- removal of accumulated sediments, litter and debris from the sedimentation chamber;
- checking to ensure the weep holes and overflow weirs are not blocked.

Maintaining the flow through a sand filter relies on 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 needs to be monitored. Depending on catchment activities (eg. building phase), sediment deposition can overwhelm the chamber and reduce flow capacities.

Debris removal is an ongoing maintenance function. If not removed, debris can block inlets or outlets, and be unsightly if located in a visible location. Inspection and removal of debris/ litter should be carried out regularly.

13.9.6 Checking Tools

This section provides a number of checking tools for designers and Council development assessment officers. In addition, **Section 13.9.5** provides general advice on the construction of sand filters and key issues to be considered to ensure their successful establishment and operation based on observations from construction projects around Australia.

The following checking tools are provided:

- Design Assessment Checklist;
- Construction Inspection Checklist (during and post);
- Operation and Maintenance Inspection Form;
- Asset Transfer Checklist (following ‘on-maintenance’ period).

Figure 13.9-C below shows the stages of the development approval, construction and establishment and asset transfer process and which checklists should be used at each stage.

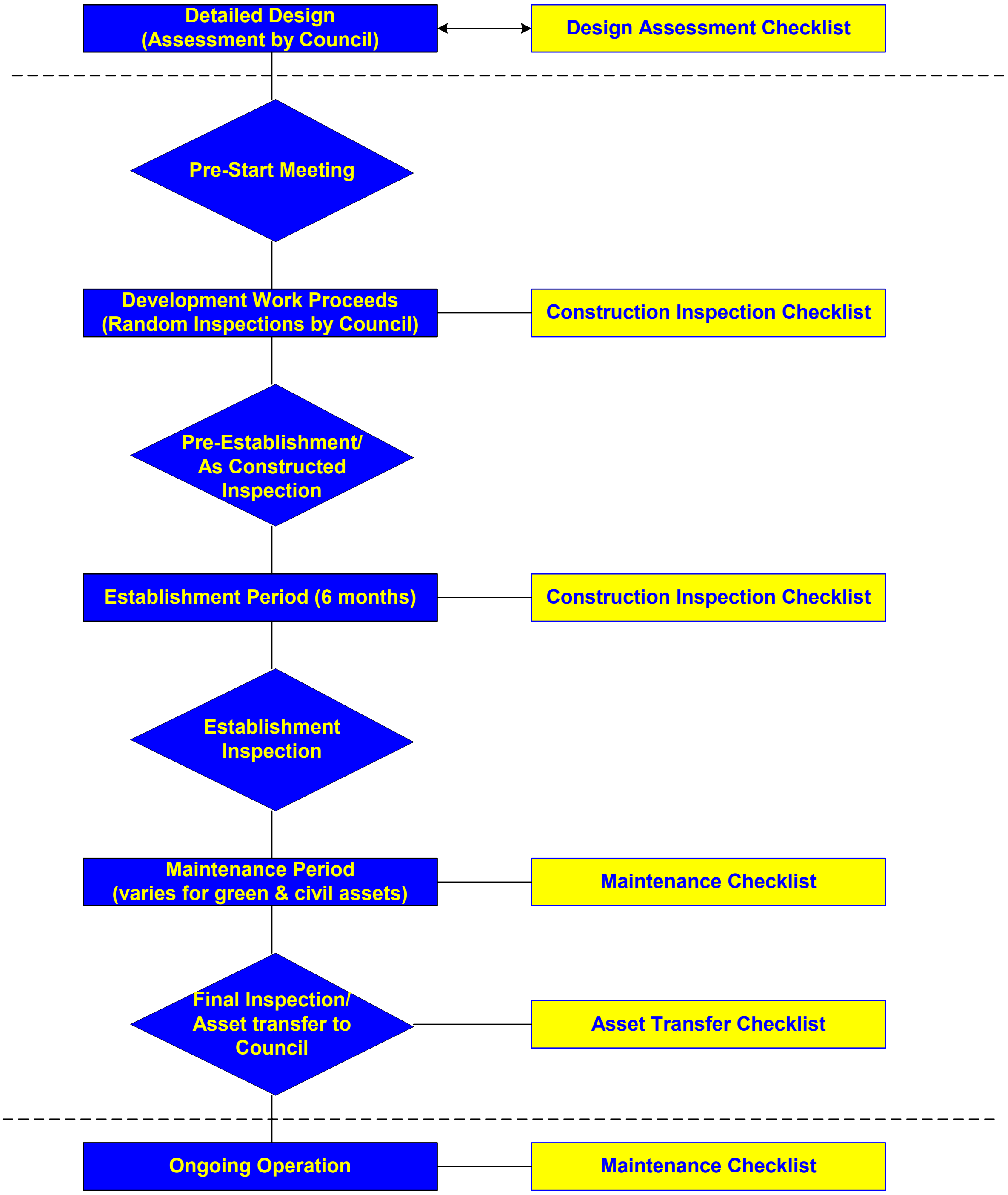


Figure 13.9-C: Development Approval and Handover Stages – Appropriate Checklists

13.9.6.1 Design Assessment Checklist

The design assessment checklist presents the key design features to be reviewed when assessing the design of a sand filter. These considerations include configuration, safety, maintenance and operational issues that need to be addressed during the design phase. If an item receives an ‘N’ when reviewing the design, referral is made to the design procedure to determine the impact of the omission or error.

In addition to the checklist, a proposed design is to have all necessary permits for its installations. Council development assessment officers will require that all relevant permits are in place prior to accepting a design.

13.9.6.2 Construction Checklist

This checklist presents the key items to be reviewed when inspecting the sand filter during and at the completion of construction. The checklist is to be used by construction site supervisors and the local authority compliance inspectors to ensure all the elements of the sand filter have been constructed in accordance with the design. If an item receives an ‘N’ in Satisfactory criteria, appropriate actions must be specified and delivered to rectify the construction issues before inspection sign-off is given.

13.9.6.3 Maintenance Checklist

This checklist should be used whenever an inspection is conducted and kept as a record on the asset condition and quantity of removed pollutants over time.

13.9.6.4 Asset Transfer Checklist

Land ownership and asset ownership are key considerations prior to construction of a stormwater treatment device. A proposed design is to clearly identify the ultimate asset owner and who is responsible for its maintenance. GCCC will use the asset transfer checklist below when the asset is to be transferred to them.

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):

Review Concept Design	**Y**	**N**
Treatment performance verified using **MUSIC**?		
Sand filter adequately clear of existing or proposed services and does not hinder access to services		
Inlet Zone/ Hydraulics	**Y**	**N**
Station selected for IFD appropriate for location?		
Configuration of sediment chamber (aspect, depth and flows) allows settling of particles >125 µm? Refer **Section 13.9.3.3**. Refer also **Section 13.5**		
Sediment chamber capacity sufficient for desilting period >=1 year? Refer **Section 13.9.3.3**. Refer also **Section 13.5**		
Scour protection provided at inlet?		
Maintenance access allowed for sediment chamber?		
Public access to system prevented?		
Drainage facilities for sediment chamber provided?		
Overall flow conveyance system sufficient for design flood event? Refer **Section 13.9.3.7**		
Velocities at inlet and within sand filter will not cause scour?		
Bypass sufficient for conveyance of design flood event? Refer **Section 13.9.3.7**		
Collection System	**Y**	**N**
Slotted pipe capacity > infiltration capacity of filter media (where appropriate)? Refer **Section 13.9.3.5**		
Maximum spacing of collection pipes <1.5 m?		
Drainage layer >200 mm?		
Transition layer provided to prevent clogging of drainage layer?		
Filter Basin	**Y**	**N**
Maximum ponding depth will not impact on public safety?		
Collection pipes extended to surface of sand to allow inspection and flushing? Refer **Section 13.9.3.5** and **Section 13.9.2.1**		
Selected filter media hydraulic conductivity > 10 x hydraulic conductivity of surrounding soil? If not, impermeable liner provided?		
Maintenance access provided to base of filter media (where reach to any part of a basin <6 m)?		
Sand media specification included in design? Refer **Section 13.9.3.4** for sand filter media characteristics		
Comments		

Sand Filter Construction Inspection Checklist

Site:		**Inspected by:**	
		Date:	
		Time:	
Constructed By:		**Weather:**	
		Contact During Visit:	

Items Inspected	**Checked**		**Satisfactory**		**Items Inspected**	**Checked**		**Satisfactory**	
	Y	**N**	**Y**	**N**		**Y**	**N**	**Y**	**N**
During Construction									
A. Preliminary Works					**C. Sedimentation Chamber**				
1. Erosion and sediment control plan adopted					12. Invert level correct				
2. Temporary traffic/ safety control measures					13. Ability to freely drain (weep holes)				
3. Location same as plans					**D. Structural Components**				
4. Site protection from existing flows					14. Location and levels of pits as designed				
B. Earthworks					15. Safety protection provided				
5. Level bed					16. Pipe joints and connections as designed				
6. Side slopes are stable					17. Concrete and reinforcement as designed				
7. Provision of liner (if required)					18. Inlets appropriately installed				
8. Perforated pipe installed as designed					**E. Filtration System**				
9. Drainage layer media as designed					19. Provision of liner				
10. Sand media specifications checked					20. Adequate maintenance access				
11. Adequate maintenance access					21. Inlet and outlet as designed				
Final Inspection									
1. Confirm levels of inlets and outlets					7. No surface clogging				
2. Traffic control in place					8. Maintenance access provided				
3. Confirm structural element sizes					9. Construction generated sediment removed				
4. Sand filter media as specified					10. Provision of removed sediment drainage area				
5. Sedimentation chamber freely drains					11. Evidence of litter or excessive debris				
6. Check for uneven settling of sand									

Comments on Inspection

Actions Required

1.

2.

3.

4.

5.

Inspection officer signature:

Sand Filter Maintenance Checklist

Inspection Frequency:	1 to 6 monthly	**Date of Visit:**	
Location:			
Description:			
Site Visit by:			

Inspection Items	Y	N	Action Required (Details)
Litter within filter area?			
Scour present within sediment chamber or filter?			
Sediment requires removal (record depth, remove if >50%)?			
All structures in satisfactory condition (pits, pipes, etc)?			
Traffic damage evident?			
Evidence of dumping (eg. building waste)?			
Clogging of drainage weep holes or outlet?			
Evidence of ponding (in sedimentation chamber or sand filter)?			
Damage/ vandalism to structures present?			
Surface clogging visible?			
Drainage system inspected?			
Removal of fine sediment required?			

Comments

Sand Filter Asset Transfer Checklist

Asset Description:	
Asset I.D.:	
Asset Location:	
Construction by:	
Defects and Liability Period:	

Treatment	**Y**	**N**
System appears to be working as designed visually?		
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 (eg. drawings, survey, models) provided?		
Asset listed on asset register or database?		

Comments

13.9.7 Sand Filter Worked Example

A sand filter system is proposed to treat stormwater runoff from a courtyard/ plaza area in Surfers Paradise on the Gold Coast. The site is nested amongst a number of 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 3500 m^2 courtyard will be directed into an underground sand filter. Provision for overflow into the underground piped drainage system ensures that the site is not subjected to flood ponding for storm events up to the 50 year ARI. The existing stormwater drainage system has sufficient capacity to accommodate the 50 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 70% of particles larger than 125 µm within the inlet zone for flows up to a 1 year ARI peak discharge;
- promote filtration of stormwater following sedimentation pretreatment through a sand layer;
- provide for high flow bypass operation by configuring and designing the bypass chamber.

The concept design suggests that the sand filter system will remove 63%, 39% and 22% of TSS, TP and TN respectively. Therefore additional treatment will be required. The concept design has suggested a required area of the sand filter chamber is 30 m^2 and the depth of the sand filter is 600 mm. Larger filter areas did not provide any additional treatment benefits when modelled in **MUSIC**. 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 (overflow chamber). Flows in excess of a 200 mm extended detention depth would overflow and discharge into the underground stormwater pipe and bypass the sand filter.

Design Objectives

Design objectives include the following:

1. Sand filter to consist of three chambers: a sedimentation (and gross pollutant trapping) chamber, a sand filter chamber and an overflow chamber.
2. The sedimentation chamber will be designed to capture particles larger than 125 µm for flows up to the peak 1 year ARI design flow with a capture efficiency of 70%. The outlet from the chamber will need to be configured to direct flows up to the 1 year ARI into the sand filter. Flows in excess of 1 year ARI will bypass to the overflow chamber.
3. The sand filter will be designed to filter the peak 1 year ARI flow. Perforated sub-soil 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.
4. The overflow chamber will be designed to capture and convey flows in excess of the 1 year ARI peak flow and up to the 50 year ARI peak discharge.
5. The sedimentation chamber will retain sediment and gross pollutants in a dry state and have sufficient storage capacity to limit sediment cleanout frequency to once a year.
6. Inlet/ outlet pipes to be sized to convey the 50 year ARI peak discharge.

Site Characteristics

The site characteristics are summarised as follows:

catchment area	3,500 m^2 (70m x 50m)
land use/ surface type	paved courtyard
overland flow slope	6.0%
soil type	clay
fraction impervious	0.90
overland flow travel path	50m

13.9.7.1 Step 1: Review Concept Design

It is assumed that earlier conceptual design of the stormwater treatment system required of this project will have undertaken appropriate modelling using **MUSIC** or alternative techniques to ensure that stormwater discharges from the site comply with GCCC water quality objectives (WQOs), a prerequisite of development approval. It is noted that subsequent additional treatment elements will be required (eg. bioretention systems) in order to enable such WQO compliance.

13.9.7.2 Step 2: Estimate Design Flows

With a small catchment (in this case 3,500 m^2), the Rational Method is considered an appropriate approach to estimate the design storm peak flow rates. The steps in this calculation follow below.

Time of Concentration (t_c)

Approach:

The time of concentration is estimated assuming overland flow across the paved courtyard. As the use of standard inlet times shall not apply in the Gold Coast City Council area, the methods outlined in **Section 5.05.5** of **QUDM** (**DPI, IMEA & BCC 1992**) are referred to.

From procedures documented in **QUDM** (**DPI, INEA & BCC 1992**) and **Section 3.5**, the overland sheet flow component should be limited to 50m in length and determined using the Kinematic Wave Equation:

$$t = 6.94\ (L.n^*)^{0.6} /\ I^{0.4}\ S^{0.3}$$

Where:

t = overland sheet flow travel time (mins)
L = overland sheet flow path length (m)
n^* = surface roughness/ retardance coefficient
I = rainfall intensity (mm/hr)
S = slope of surface (m/m)

In urban areas, **QUDM** notes that sheet flow will typically be between 20 to 50m, after which the flow will become concentrated against fences, gardens or walls or intercepted by minor channel or piped drainage (**DPI, IMEA & BCC 1992**). Therefore when calculating remaining overland flow travel times, it is recommended that stream velocities in **Table 5.05.4** of **QUDM** be used.

Assuming: Predominant slope = 6%

Overland sheet flow = 50m

Flow path is predominately paved, with a typical n* = 0.013 (**QUDM**)

10 year ARI:

$$t_{\text{sheet flow}} = 6.94\ (50 \times 0.013)^{0.6} / (I^{0.4} \times 0.06^{0.3})$$

$$= < 5 \text{ mins}$$

Therefore adopt a 5 minute time of concentration in line with the **Section 3.5**.

Iterations will usually need to be repeated until $t_{sheet\ flow}$ matches 10 year ARI rainfall intensity on the IFD chart for that duration. However, in this case the time of concentration is very low for all ARIs, and therefore a 5 minute time of concentration is adopted for all design events.

Note: IFD data will need to be determined in line with Section 3.5.7.6.

Design Runoff Coefficient

Runoff Coefficients

C_{10} = 0.95 (commercial – refer to **Section 3.5**)

	C Runoff			
ARI	1	2	10	50
QUDM Factor	0.8	0.85	1	1.15
C_{ARI}	0.76	0.81	0.95	1.00

Catchment Area

A $= 3{,}500\ m^2$ (0.35ha)

Rainfall Intensities (GCCC IFD for Surfers Paradise)

t_c = 5 mins

I_1 = 122.8 mm/hr

I_{10} = 193mm/hr

I_{50} = 239.3 mm/hr

Rational Method Q = *CIA*/360

$Q_{1yr\ ARI}$ $= 0.091\ m^3/s$

$Q_{10yr\ ARI}$ $= 0.178\ m^3/s$

$Q_{50yr\ ARI}$ $= 0.223\ m^3/s$

Maximum Infiltration Rate

The maximum infiltration rate (Q_{max}) through the sand filter is computed using **Equation 8.1**:

$$Q_{max} = K_{sat} \cdot A \cdot \frac{h_{max} + d}{d} \qquad = 0.04\ m^3/s$$

Where:

K_{sat} = is the hydraulic conductivity of coarse sand = 1×10^{-3} m/s (Engineers Australia 2003)

A = is the surface area of the sand filter = 30 m^2

h_{max} = depth of pondage above the sand filter = 0.2m

d = depth of the sand filter = 0.6m

Design Flows

$Q_1 = 0.091\ m^3/s$; Q10 $= 0.178\ m^3/s$; Q50 $= 0.223\ m^3/s$

Maximum Infiltration Rate $= 0.04\ m^3/s$

13.9.7.3 Step 3: Design Inflow Systems

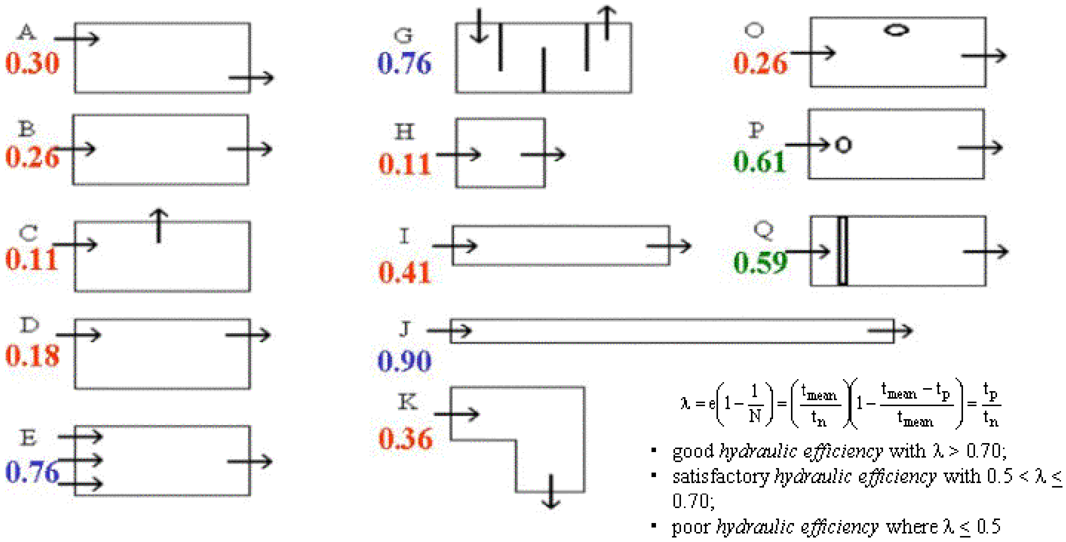
a) Sedimentation Basin Chamber

The sedimentation chamber is to be sized to remove the 125 µm particles for the peak 1 year ARI flow.

Pollutant removal is estimated using **Equation 13.5.1** (see **Section 13.5**):

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

A notional aspect ratio of 1 (W) to 2 (L) is adopted. From **Figure 4.4** in **Section 4** (reproduced below), the hydraulic efficiency (λ) is estimated to be 0.3. The turbulence factor (n) is computed from **Equation 4.2** to be 1.4.



$$\lambda = e\left(1-\frac{1}{N}\right)=\left(\frac{t_{mean}}{t_n}\right)\left(1-\frac{t_{mean}-t_p}{t_{mean}}\right)=\frac{t_p}{t_n}$$

- good *hydraulic efficiency* with $\lambda > 0.70$;
- satisfactory *hydraulic efficiency* with $0.5 < \lambda \leq 0.70$;
- poor *hydraulic efficiency* where $\lambda \leq 0.5$

Source: Reproduced from **Section 13.5**.3.3

Figure 13.9-D: Hydraulic Efficiency

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

The proposed extended detention depth of the basin is 0.2m (as outlined in **Section 13.9.6.1**) and a notional permanent pool depth of 0.6 m (equal to the depth of the sand filter) has been adopted:

d_p = 0.6 m
d^* = 0.6 m
d_e = 0.20 m
v_s = 0.011 m/s for 125 µm particles (settling velocity)
Q = Design flow rate = 0.091 m^3/s

The required sedimentation basin area to achieve target sediment (125 µm) capture efficiency of 70% is 16 m^2. With a W to L ratio of 1:2, the notional dimensions of the basin are 3 m x 5.5 m = 16.5 m^2.

The available sediment storage (V_s) is 16.5 x 0.6 = 9.9 m^3. Cleanout is to be scheduled when the storage is half full. Using a sediment discharge rate (Q_{sed}) of 1.6 m^3/Ha/yr (**Engineers Australia 2003**) and a catchment area (A_c) of 0.35 ha, we have:

Frequency of basin desilting:

$$\boxed{\frac{50\% \times V_s}{A_c \text{ x } Q_{sed} \times \text{capture efficiency}}}$$

$$= \frac{0.5 \times 9.9}{0.35 \times 1.6 \times 0.7} = 12.6 \text{ years} > 1 \text{ year} \Rightarrow \text{OK}$$

During the 50 year ARI storm, peak discharge through the sedimentation chamber will be 0.223 m^3/s with flow depth of 0.8m and a chamber width of 3m. It is necessary to check that flow velocity does not resuspend deposited sediment of 125 µm or larger (≤ 0.5 m/s).

The mean velocity in the chamber is calculated as follows:

$$v_{50} = 0.223/(3 \text{ x } 0.8) = 0.1 \text{ m/s} \Rightarrow \text{OK}$$

The length of the sedimentation chamber is 5.5m. Provide slots of total length of 2m connecting it to the sand filter chamber. The connection discharge capacity should be greater than the 1 year ARI peak flow (0.091 m^3/s) and can be calculated using **Equation 13.9.4** as follows:

$$Q_{conn} = C_w \cdot L \cdot h^{3/2}$$

Where:

Q_{conn} = flow rate through connection (m^3/s)

C_w = weir coefficient (assume = 1.4 for a broad crested weir)

h = depth of water above the weir = 0.2m (extended detention in sedimentation chamber)

L = length of the weir (m)

The discharge capacity calculated from the above equation is:

0.25 m^3/s >> 1 year ARI discharge of 0.091 m^3/s

Sedimentation Chamber = 16.5 m^2

Width = 3m

Length = 5.5m

Total weir length of connection to sand filter chamber (minimum) = 2m

Depth of chamber from weir connection to sand filter = 0.6m

Depth of Extended Detention (d_e) = 0.2m

b) Sand Filter Chamber

Dimensions

With the length of sedimentation chamber being 5.5m, the dimension of the sand filter chamber is determined to be 5.5m x 6.0m, giving an area of 33 m^2.

Sand filter chamber dimension: 4.5m x 6.0m

13.9.7.4 Step 4: Specify Filter Media Characteristics

Sand filter layer is to consist of sand/ coarse sand material with a typical particle size distribution as provided below:

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

- filter layer is to be 600 mm deep and consist of sand with 80% greater than 1 mm diameter;
- the drainage layer is to consist of fine gravel, of 5 mm screenings and consist of 5 mm gravel.

13.9.7.5 Step 5: Under-drain Design

a) Perforations Inflow Check

The following are the characteristics of the selected slotted pipe:

Clear Openings = 2100 mm^2/m

Slot Width = 1.5mm

Slot Length = 7.5mm

No. Rows = 6

Diameter of pipe = 100mm

For a perforated pipe,

Total number of slots = 2100/(1.5 x 7.5) = 186 per metre

Discharge capacity of each slot can be calculated using the orifice flow equation (**Equation 13.9.2**):

$$Q_{perf} = C_d \cdot A \cdot \sqrt{2 \cdot g \cdot h}$$

Where:

Q_{perf} = flow through perforations (2.67 x 10-5 m^3/s)
h = hydraulic head above the slotted pipe (0.80m)
C_d = orifice discharge coefficient (~0.6)

The inflow capacity of the slotted pipe is thus:

$2.67 \times 10^{-5} \times 186 \sim 5 \times 10^{-3}$ m^3/s/m-length

Adopt a blockage factor of 0.5 giving the inlet capacity of each slotted pipe to be:

2.5×10^{-3} m^3/s/m-length

Maximum infiltration rate is 0.04m^3/s

The minimum length of slotted pipe required is:

$L_{slotted\ pipe} = 0.04/2.5\text{x}10^{-3} = 16$m

With a maximum spacing of 1.5m centre to centre, this equates to 4 lengths of 5.5m at 1.5m spacing (0.75m from the edges). Therefore a total pipe length of 22m is used. The total flow through the perforations can now be calculated:

Q_{perf} = 22m x 2.5 x 10^{-3} m^3/s/m
= 0.055 m^3/s

Check total flow through perforations:

0.055 m^3/s > max flow through filtration media 0.04 m^3/s ➔ OK

Four (4) 100 mm diameter slotted pipes (5.5m lengths each) at 1.5m spacing are required.

b) Perforated 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 13.9.3**):

$$Q_{pipe} = C_d \cdot A_{pipe} \sqrt{2 \cdot g \cdot h}$$

Where:

Q_{pipe} = flow through pipe(s) = (0.019 m^3/s)
C_d = orifice discharge coefficient (~0.6)
A = area of the pipe(s) (4 pipes x 0.00785 m^2 per pipe)
g = gravity (9.81 m/s^2)
h = depth of water over the collection pipe (0.8m)

Total discharge capacity:

(4 pipes) = 0.07 m^3/s > maximum infiltration rate of 0.04 m^3/s ➔ OK

Combined slotted pipe discharge capacity = 0.07 m^3/s which exceeds the maximum infiltration rate.

13.9.7.6 Step 6: Requirements for Impermeable Lining

No impervious liner is necessary as *in-situ* soil is clay and the sand will have at least 100 times higher hydraulic conductivity that the *in-situ* soils.

13.9.7.7 Step 7: Size Overflow Weir

The width of the sedimentation chamber has been selected to be 3m. An overflow weir set at 0.8m from the base of the sedimentation chamber (or 0.2m above the surface of the sand filter) of 2.5m length needs to convey flows up to the 50 year ARI peak discharging into the overflow chamber.

Calculate the depth of water above the weir resulting from conveying the 50 year ARI peak discharge through a 2.5m length weir by rearranging **Equation 13.9.4**:

$$h = \left(\frac{Q_{weir}}{C_w \cdot L} \right)^{2/3} = 0.13 \text{ m, say } 0.15 \text{ m}$$

Where:

Q_{weir} = design discharge = 0.233 m^3/s

C_w = weir coefficient (~1.7)

L = length of the weir (m) = 3m

h = depth of water above the weir (m)

With a depth above the weir of 0.15m, the discharge capacity of the overflow weir is 0.3 m^3/s > 50-year ARI peak flow of 0.23 m^3/s

Crest of overflow weir = 0.2m above surface of sand filter

Length of overflow weir = 3m

50 year ARI weir flow depth = 0.15m

Roof of facility to be at least 0.35m above sand filter surface.

13.9.7.8 Design Calculation Summary

The table below shows the calculation summary for the worked example.

Drawing 13.9.1 shows the principles of this worked example.

Sand Filter	Calculation Summary		
Calculation Task	**Outcome**		**Check**
Catchment Characteristics			
Catchment Area	0.35	Ha	✓
Catchment Land Use (ie. Residential, Commercial, etc)	0.9 impervious		
Storm Event Entering Inlet	50	yr ARI	
Conceptual Design			
Sand Filter Area	30	m^2	✓
Filter Media Saturated Hydraulic Conductivity	3600	mm/hr	
Extended Detention Depth	0.2	mm	
1 Review Conceptual Design			
MUSIC Modelling Results			
Total Suspended Solids	63	%	✓
Total Phosphorus	39	%	
Total Nitrogen	22	%	
Sand filter area	30	m^2	✓
Extended detention depth	0.2	m	
2 Determine Design Flows			
Time of Concentration			
Refer to **GCCC Land Development Guidelines** and **QUDM**	5	minutes	✓
Identify Rainfall Intensities			
$I_{1 \text{ year ARI}}$	122.8	mm/hr	✓
$I_{2 \text{ year ARI}}$	193	mm/hr	
$I_{50 \text{ year ARI}}$	239.3	mm/hr	
Design Runoff Coefficient			
$C_{1 \text{ year ARI}}$	0.76		✓
$C_{2 \text{ year ARI}}$	0.95		
$C_{50 \text{ year ARI}}$	1.00		
Peak Design Flows			
1 year ARI	0.091	m^3/s	✓
2 year ARI	0.178	m^3/s	
50 year ARI	0.233	m^3/s	
$Q_{\text{infiltration}}$	0.04	m^3/s	
3 Design Sedimentation Chamber			
Required Surface Area?	16	m^2	✓
Length x Width	3.0 x 5.5	m	
Depth	0.6	m	
Design Particle Size	0.125	mm	
Check SCOUR VELOCITY (<0.5 m/s ?)	0.1	m/s	
Check OVERFLOW CAPACITY?	0.25	m^3/s	
4 Specify Sand Filter Media Characteristics			
Filter Media Hydraulic Conductivity	3600	mm/hr	✓
Filter Media Depth	0.6	mm	
Drainage Layer Depth	0.2	mm	
Provided Specification for Sand Media?	Yes		
5 Design and Check Under-Drainage			
Flow Capacity of Filter Media	0.04	m^3/s	✓

Sand Filter	Calculation Summary		
Calculation Task	**Outcome**		**Check**
Perforations Inflow Check			
Pipe Diameter	100	mm	✓
Number of Pipes	4		
Capacity of Perforations	0.055	m^3/s	
Check PERFORATION CAPACITY > FILTER MEDIA CAPACITY	Yes		
Perforated Pipe Capacity			
Pipe Capacity	0.07	m^3/s	✓
Check PIPE CAPACITY > FILTER MEDIA CAPACITY	Yes		
6 Check Requirement for Impermeable Lining			
Soil Hydraulic Conductivity	0.36	mm/hr	✓
Filter Media Hydraulic Conductivity	3600	mm/hr	
More than 10 TIMES HIGHER than *IN-SITU* SOILS?	Yes		
7 Size Overflow Weir			
Design Storm for Overflow (eg. 2yr ARI)	50 year		✓
Weir Length	3	m	
Depth of Flow Over Weir	0.15	m	
Discharge Capacity of the Overflow Weir	0.3	m^3/s	
Design Storm Discharge	0.233	m^3/s	
Check Discharge Capacity of the Overflow Weir > $Q_{design\ storm}$	yes		

13.9.8 References

ARC (Auckland Regional Council) 2003, **Stormwater Management Devices: Design Guidelines Manual**, ARC, New Zealand.

CRCCH (Cooperative Research Centre for Catchment Hydrology) 2005, **MUSIC User Manual**, Version 3.0, CRCCH, Melbourne.

DPI, IMEA & BCC (department of Primary Industries – Water Resources, Institute of Municipal Engineers Australia – Qld Division & Brisbane City Council) 1992, **Queensland Urban Drainage Manual (QUDM)**, prepared by Neville Jones & Associates and Australian Water Engineering for DPI, IMEA & BCC, Brisbane.

Engineers Australia 2003, **Australian Runoff Quality**, Engineers Australia, ACT, http://www.arq.org.au/ .

Institution of Engineers Australia 1997, **Australian Rainfall and Runoff – A Guide to Flood Estimation**, Institution of Engineers Australia, ACT.