WATER SENSITIVE URBAN DESIGN

PRACTICE GUIDE

FINAL

Prepared for the Northern Territory Department of Planning and Infrastructure
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1 Introduction

This "WSUD Practice Guide" is intended to assist in the selection, sizing and conceptual design of potable water conservation and stormwater quality treatment measures as part of a WSUD Strategy for a new subdivision. It is intended to guide:

- Consideration of alternative strategies to meet the Darwin Harbour WSUD objectives
- Selection of appropriate water cycle management measures for a greenfield subdivision development
- Initial sizing, location and conceptual design of water cycle management measures
- Integration of water cycle management measures with the urban design

Figure 1 shows how this document relates to the other WSUD guidelines and tools being developed as part of the Darwin Harbour WSUD Strategy to assist with the implementation of WSUD. Documents currently available are highlighted in blue.

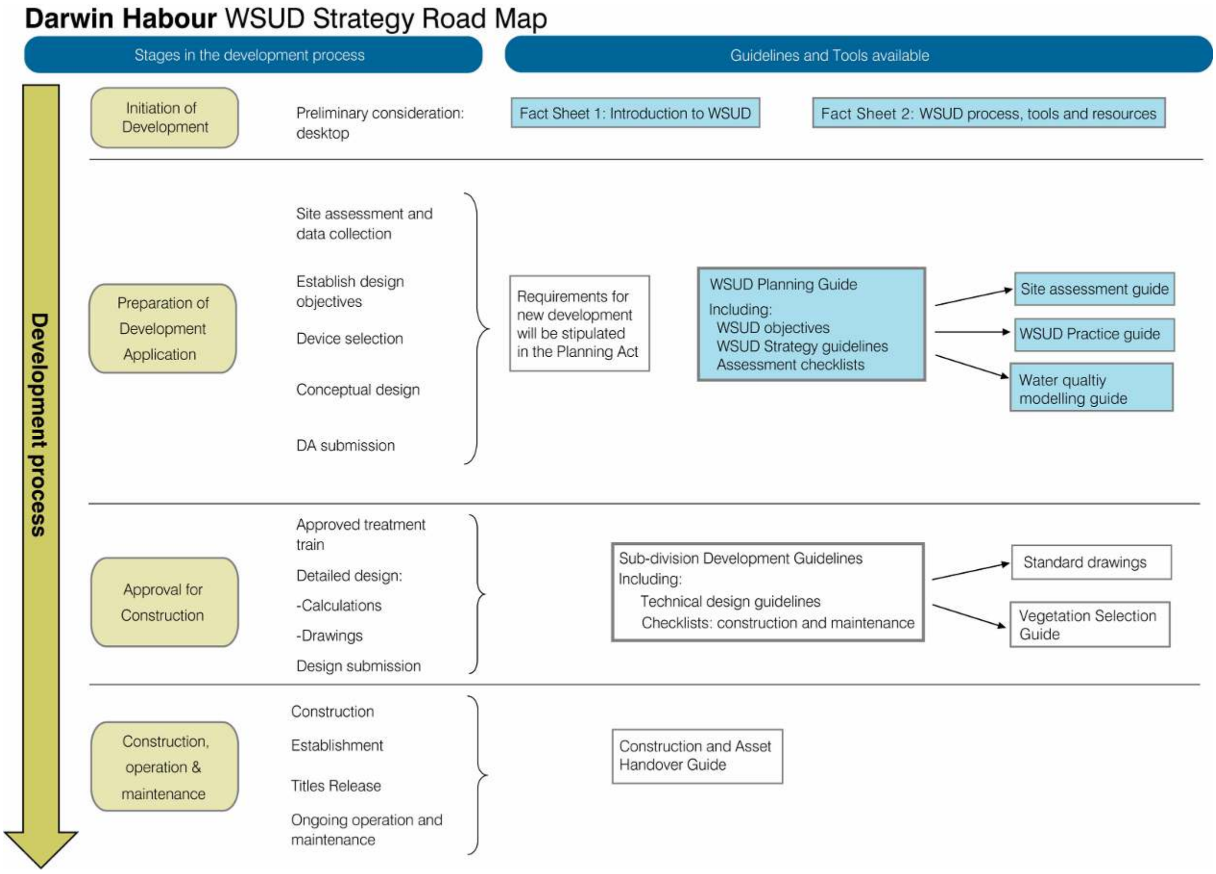


Figure 1: Relationship of the "WSUD Practice Guide" to other guidelines and tools

In order to achieve the objectives for Darwin Harbour, a range of WSUD measures may be required:

- Water conservation measures including demand management measures, water recycling and stormwater harvesting and reuse
- Stormwater quality treatment measures including swales, wetlands and bioretention systems

The following sections of this document outline the function of these WSUD measures, including rainwater tanks, water recycling systems, stormwater harvesting and reuse schemes, swales, bioretention systems, wetlands, gross pollutant traps and stormwater infiltration. Each section provides information useful at the device selection, sizing and concept design stage, including:

- The purpose of each element and how it works
- Where it would be most appropriately located in the urban landscape
- Important design considerations, including soil and vegetation selection for vegetated stormwater treatment measures. The design considerations point to the advantages and disadvantages, benefits and risks of each WSUD measure
- Basic sizing information suitable for preliminary estimates
- Maintenance requirements
- References to further information are provided where relevant.

A WSUD Strategy for a development will normally include some demand management and potable water substitution elements; it is also likely to include a combination of at least two or more different types of stormwater treatment methods and may also include a stormwater harvesting and/or wastewater reuse component, depending on the opportunities at the particular site.

Table 1 provides an outline guide to the selection and use of water cycle measures to meet the Darwin Harbour WSUD objectives. It indicates where to find further information on each measure.

Table 1: Summary of key methods available to meet the WSUD DCP objectives

Objectives	Water cycle management measure	Section
Water conservation	Demand management	Section 2.1
	Rainwater tanks	Section 2.2
	Water recycling	Section 2.3
	Stormwater harvesting, storage and reuse	Section 2.4
Stormwater quality	Vegetated swales and buffer strips	Section 3.1
	Bioretention systems	Section 3.2
	Wetlands	Section 3.3
	Gross Pollutant Traps	Section 3.4
	Infiltration	Section 3.5

2 Water conservation

Potable water is supplied to the Darwin Region by the Power and Water Corporation. Darwin's principle water supply is the Darwin River Dam which supplies approximately 90% of Darwin's potable water supply. Supplementary supplies are available from Manton Dam and the McMinns borefield.

Darwin residents use twice as much water per head as people in other capital cities (PWC, 2006b). The average consumption per person, including government and industry related water use, is 960 L/person/day. Of this demand, 65% is associated with irrigating landscape in the dry season. Water use data for the Darwin Region is summarised in Figure 2.

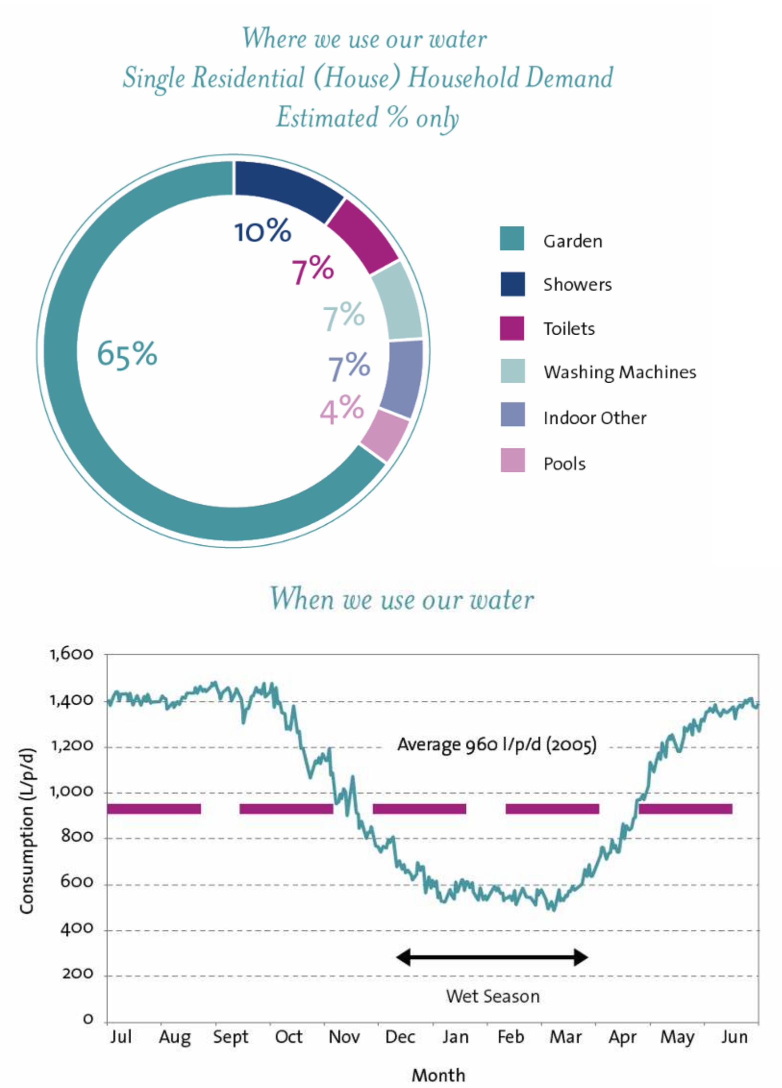


Figure 2: Water use in the Darwin Region (Power and Water Corporation, 2007)

This extreme demand for water combined with rapid population growth has resulted in overall water demand (40GL/yr) reaching the current supply capacity of Darwin River Dam and Howard East/McMinns borefield (46GL/yr). Projected future population growth of between 120,000 – 260,000 people is expected to increase demand to approximately 70GL/yr and meeting this demand will require a range of initiatives.

The household water use breakdown shown in Figure 2 indicates that the most significant opportunity for water conservation in residential development is to reduce water demand in the garden. Toilets, washing machines and hot water supplies also represent significant demands which can be supplied with rainwater and/or recycled water.

Most potable water used indoors is discharged as wastewater. An indicative estimate of the wastewater volume generated in Darwin is 30 to 35% of the water consumption. Wastewater in Darwin is treated using Waste Stabilisation Ponds (WSPs) at five separate treatment plants and discharged to Darwin Harbour: Treated wastewater is discharged to the ocean via offshore outfalls at Norah Head and Bateau Bay.

Potable water conservation therefore contributes to both:

- Reduced demand on water resources, including the Darwin River and rural Darwin groundwater resources
- Reduced wastewater discharges into Darwin Harbour

In new development, water conservation can be achieved by demand management and/or potable water substitution with alternative water sources. Table 3 summarises alternative water sources typically available in urban areas and their relative quality and treatment requirements. Generally, schemes that supplement potable supply will try to use higher quality water sources in preference to lower, as the treatment requirements are simpler and less costly. Further information is provided in this document on rainwater harvesting (Section 2.2), water recycling (Section 2.3) and stormwater harvesting (Section 2.4).

Table 3: Summary of water quality in the urban water cycle

Water type	**Source**	**Quality**	**Treatment required**
Potable mains water	Reticulated (piped) water distribution	High quality	None
Rainwater	From roof during rain, generally stored in rainwater tanks	Reasonable quality	Low. Sedimentation can occur inside rainwater tanks
Stormwater	Catchment runoff, including impervious areas like roads and pavements	Moderate quality	Reasonable treatment needed to remove litter and reduce sediment and nutrient loading
"Light" greywater	Showers, baths, bathroom basins	Cleanest wastewater – low pathogens and low organic content	Moderate treatment required to reduce pathogens and organic content
Greywater	As above, plus laundry water, including basin and washing machine	Low quality – high organic loading and highly variable depending on how it was used	High level of treatment required to reduce pathogens and organic content
Blackwater	As above, plus kitchen, and toilet. Can also be sourced from sewers	Lowest quality wastewater – high levels of pathogens and organics	Advanced treatment and disinfection required

2.1 Demand Management

Demand management reduces the total consumption of water. Demand management is typically the most cost effective method to conserve water and thus should be considered a key component of all WSUD strategies. Demand management includes both structural, such as the installation of water efficient fixtures, and non-structural measures, such as education campaigns to reduce water use.

A recent survey undertaken by Power and Water Corporation (PWC) has shown there is widespread community support for demand management initiatives. The survey found that:

- More than half of all residents and businesses believe that water conservation in Darwin is critical
- Residents and businesses agree that it is socially responsible for them to monitor water use
- Mandatory water efficient devices in new buildings and residences is the first preference to encourage water efficiency.

2.1.1 Location

In new developments demand management is readily applied at the building scale. For example households consume a large portion of water within developments and many demand management measures, such as water efficient toilets, shower heads and taps, are most appropriately applied for individual dwellings. Demand management is also readily applied in commercial, retail, government and community buildings.

Application of demand management within public buildings, such as schools, government buildings and community centres should be a key focus for demand management. Application of structural demand management measures should be integrated with non-structural measures such as education and information campaigns to raise awareness of water conservation and its role in Darwin's water supply.

Due to the significant consumption of water for irrigation demand management is also readily applied in public open space and private landscapes. Some demand management measures can be applied at all scales, such as the selection of low water use vegetation, and irrigation of public open space outside the peak evaporation hours. Other demand management measures are most suited to application at larger scales, such as the adoption of sophisticated irrigation systems with irrigation controllers.

2.1.2 Design Considerations

The key design consideration in Darwin for conservation of potable water is the reduction of outdoor water use. A demand management strategy should have a strong focus on reducing outdoor water consumption due to the large percentage of consumption that is used for irrigation.

Another key design consideration for demand management in Darwin is the ability to influence water consumption on the lot scale. Due to the nature of development most WSUD strategies deal directly with the provision of civil and public infrastructure such as roads, drainage, water and wastewater systems and public open space. Development of private infrastructure means that components of a WSUD strategy will be required to be implemented through development control policies or education and incentives rather than through direct physical provision of infrastructure.

Demand management practices are relatively simple and well established. A summary of demand management opportunities and the design considerations is included in Table 2.

Table 2: Key demand management opportunities associated with new development

Buildings	Within buildings, the key demand management opportunity is the use of water-efficient fittings and appliances. The Water Efficiency Labelling and Standards Scheme (WELS, http://www.waterrating.gov.au/) provides a good guide to the availability and water use of fittings and appliances. Water efficient fittings and appliances include: • Tap fittings • Toilets and urinals • Shower heads • Washing machines and dishwashers
Open space	Currently there are no accepted best practice guidelines for xeriscaping (landscaping for minimal water use) or urban irrigation; however it is known that irrigation water demands are affected by a large number of factors, and the following structural measures can be taken to reduce water demands: • Choose native species with low irrigation demands • Use mulch in landscaped areas to reduce evaporation from the soil • Use good quality topsoil and aerate the topsoil regularly (particularly at sports fields) • Where turf is required, use warm season grasses • Use subsurface or drip irrigation for more efficient water application • Locate landscaped areas where they will receive passive irrigation from natural runoff As well as structural measures, irrigation use is strongly influenced by cultural practices and water use can be significantly reduced through the adoption of more efficient non-structural practices: • Ensuring high efficiency application by reducing water loss through drift, evaporation, or runoff from pervious surfaces • Irrigation during the night when evaporation is lowest • Application of correct volumes of water, rather than overwatering • Activating irrigation systems only when required (eg ensuring that automatic irrigation systems do not irrigate during the wet season) Where possible landscape should be located and designed such that they are integrated into the water cycle at a site and are not dependent on potable water for irrigation.

2.1.3 Maintenance

Maintenance of many demand management features such as water efficient showerheads and toilets, are similar to the maintenance required for non-water efficient devices. Water efficient fixtures and appliances adopted within the building are very low maintenance. The maintenance of water efficient landscapes is also similar to non-water efficient landscapes and in many cases can be less with reduced water requirement and reduced fertilizer application.

There is low to moderate maintenance requirements for water efficient irrigation systems depending on the complexity of the system. In general the more complex systems are more appropriate for open space that has dedicated maintenance staff. Maintenance for irrigation systems consists of:

- appropriate startup at the beginning of the dry season and shutdown procedures at the end of the dry season
- ensuring irrigation systems are free of any blockages (particularly important for sub-surface irrigations)
- inspecting and ensuring any timers are operating correctly and scheduling timers appropriately for weather conditions
- inspecting and ensuring sensors are correctly calibrated
- replacing any broken components of irrigation systems due to wear and tear
- ensuring any sprinkler heads are not blocked by vegetation
- repairing any leakages in the irrigation system
- ensuring all irrigation is directed to pervious surfaces away from paved areas and roads

2.1.4 Further Information

Power and Water Corporation have provided a number of good information sources to promote demand management and water conservation in the Darwin Region. In particular PWC have produced the following two documents:

- "How to create a water wise garden in the Top End" which provides information on local native species, irrigation practices, and irrigation systems which reduce water consumption for outdoor use for irrigation.
- "Green Guide" which provides information on choosing water efficient fixtures and appliances and using simple water saving practices around the home

Also the Northern Territory Government and Power and Water are currently working with the "SaveWater!" Alliance to establish a water conservation program. The program will provide a centralised education and information resource for anyone wanting to reduce water consumption while maximising economic or commercial opportunities.

Other national resources that are useful for demand management include the

- Water Efficiency and Labelling Scheme (http://www.waterrating.gov.au) which provides a valuable database of water efficient products
- Australian Government's Your Home Technical Manual (http://www.yourhome.gov.au/technical/fs20.htm) which provides information on a number of measures to reduce potable water demand by good design.

2.2 Rainwater Tanks

Rainwater is runoff from roofs, which can be captured and used without treatment for toilet flushing, irrigation, washing machines and hot water systems. Rainwater storage tanks can be incorporated into new or existing buildings and open space areas so that they do not impact on the aesthetics of the building or landscaped areas. A wide variety of materials, shapes and sizes are available

2.2.1 Location

Rainwater tanks are most commonly located aboveground on private lots. They are typically located outdoors and close to dwellings to capture rainwater from a downpipe or multiple downpipes.

Rainwater tanks can be installed above or underground but typically are installed aboveground where space permits due to the extra cost involved in excavation and more stringent back flow prevention requirements when locating tanks below ground.

Rainwater tanks can also be incorporated into building design so they do not impact on the aesthetics of a development or surrounding environment or where space is not available for rainwater tanks, for example some slim line designs incorporate tanks into fence or wall elements, as shown in Figure 6.

Figure 6: Rainwater tank designs

2.2.2 Design considerations

Rainwater tanks are not appropriate for substitution of potable water for irrigation in Darwin. Irrigation demands in Darwin are very high during the dry season while during the wet season little or no irrigation occurs. Large rainwater tanks would be required to capture and store significant volumes of water during the wet for use during the dry season. The tank sizes required are not feasible on typical urban lots and are also more costly. Hence, in the wet dry tropics, rainwater tanks are best suited to the replacement of indoor potable water demands.

Despite the high seasonality of rainfall in the Darwin region significant volumes of rainwater can still be harvested during the wet season. Rainwater tanks are effective in Darwin when connected to high volume indoor uses such as washing machines and hot water services.

The high volumes and high reliability of rainfall during the wet season means that rainwater tanks will supply almost all of the internal non-potable end-use demands during the wet season. This high reliability for up to six months of the year compensates for the lack of rainfall during the three to four months during the dry season when no demands are being supplied by rainfall.

Rainwater tanks should be the right size for the associated roof area and water demands. Rainwater tanks are most effective when they are sized efficiently and the demands are well-matched to the available runoff from the roof area. For the Darwin region and its particular climate and end use demands:

- the most efficient tank size that balances yield with roof size, climate and demand scenario is a 1 to 2 kL tank.
- Rainwater tanks to be effective need to be connected to high volume indoor uses such as washing machines and/or hot water services

A summary of the potable water that can be conserved through adoption of a rainwater for a typical single dwelling in the Darwin region is shown in Table 3.

Table 3 Summary of potable water savings through the adoption of rainwater tanks

End Use	1 kl Rainwater Tank	2 kl Rainwater Tank
Toilet and Laundry	9% (40 kL)	10% (43 kL)
Toilet, Laundry and Irrigation	13% (59 kL)	14% (63 kL)
Toilet, Laundry and Hot Water	14% (63 kL)	18% (78 kL)
Toilet, Laundry, Hot Water and Irrigation	18% (79 kL)	20% (87 kL)

Rainwater tanks if not installed or maintained properly can be an ideal breeding site for mosquitoes that spread serious illnesses such as dengue fever. Rainwater tanks in the Darwin environment need to ensure that inlets and outlets to rainwater tanks prevent access to mosquitoes. Design guidelines have been developed to prevent mosquito access, such as those in the Queensland Building Code. These guidelines are a good resource for installation of rainwater tanks in the Darwin region In summary, due to the significant yields of rainwater systems during the wet season, there is a realistic possibility of reduction of demand placed on reticulated water supplies from rainwater tanks, especially if no other non-potable source is available. These significant savings can alleviate the need for additional supply systems (such as new dams) for high growth urban areas.

Rainwater tanks can be fitted with 'first flush diverters'. These are simple mechanical devices that divert the first portion of runoff volume (that typically carries more debris and contaminants) away from the tank. After the first flush diversion, water passes directly into the tank.

Tanks can also be fitted with potable water top-up devices, to ensure there will always be some water in the tank, even in periods of no or little rainfall. This is important if rainwater is used for indoor demands. Potable water top-up is achieved by plumbing potable water into the tank with an air gap, having a float activated switch as well as ensuring no cross contamination can occur by using appropriate valves. Where there is potable water top-up, a backflow prevention device is required to prevent rainwater from entering the potable supply system.

Collected roof runoff water is suitable for direct use for non potable indoor uses including toilet flushing and laundries with no additional treatment. Tank water can also be used in hot water systems, where a storage temperature of 60°C will effectively destroy most pathogens in a short amount of time. Australian Standard (*AS/NZS 3500 Part 4.2*) requires hot water to be stored at a minimum of 60°C and then mixed with cold water to be delivered at 50°C. Following these standards should ensure effective pathogen removal for hot water use. If pathogens are a particular concern, then chemical or UV disinfection could also be used.

A licensed plumber is typically required to install the rainwater tank with all installations conforming to Australian standards (*AS3500.1.2 Water Supply: Acceptable Solutions*)[1].

2.2.3 Maintenance

Rainwater tanks involve regular preventative maintenance in order to avoid the need for corrective action. Recommended maintenance includes:

- 6-monthly inspections of roof areas and gutters to ensure they are relatively free of leaves and debris.
- Vegetation and trees that overhang the roof may need to be pruned.
- First flush devices should be checked and cleaned out once every 3-6 months.
- Bypass screens at inlet and overflow points should be inspected each 6 months to check for fouling and clean them.

[1] Refer to the Green Plumbers (www.greenplumbers.com.au) for additional information

- Every 2-3 years, tanks should be checked for accumulation of sludge. Sludge may become a problem if it is deep enough to reach the level of the out take pipe and so produce discoloured or sediment-laden water, or when it affects storage capacity. When necessary, sludge can be removed by vacuum, by siphon, by suspending the sludge and washing it through, or by completely emptying the tank.

- If a pump system is used, the pump manufacturer should be consulted for advice on necessary maintenance.

2.2.4 Further Information

Information on modelling rainwater tanks in MUSIC is included in the *WSUD Technical Guidelines*

The enHealth document *Guidance on Use of Rainwater Tanks* (Australian Government, 2004) provides information on health-related issues associated with rainwater tanks.

2.3 Water Recycling

Treated wastewater which is beneficially reused is referred to as reclaimed water or recycled water. Recycled water can refer to either greywater or blackwater recycling. Greywater and blackwater have a constant and predictable flowrate which improves the reliability of recycled water as an alternate supply of water; however recycled water requires treatment to get to an appropriate standard for reuse.

Greywater

Greywater from residential and commercial areas (water from the laundry, bathroom taps and shower) along with industrial greywater (slightly polluted water reused in manufacturing or other industrial processes) is a potential water source that can be reused with less treatment than blackwater.

Greywater contaminants include: low levels of bacteria, faecal matter, organic matter, micro-organisms, salts and detergents. All of these contaminants can contribute to colour and odour. Depending on the reuse application, a high level of treatment, including screening, sedimentation, biological treatment and disinfection, may be required. However where public access is limited, treatment requirements are typically lower. For example it may be possible to divert greywater to sub-surface irrigation with minimal treatment.

Reuse of greywater requires that greywater is separated from blackwater at source. This may be feasible in new high density developments or at individual industrial sites, but is difficult to retrofit or to apply on a regional scale, so it generally relies on individual households to take up the initiative.

The approval process for greywater reuse in the Darwin Region for single dwellings is outlined in the Environmental Health Bulletin on “Permanent Greywater Reuse in Single Domestic Premises” . The Bulletin identifies two main methods of reusing greywater for domestic purposes:

1. greywater diversion devices (GDDs) – a permanent greywater diversion whereby a greywater source is plumbed either through gravity or pump to a below ground irrigation system. Once a GDD has been approved by the Department of Health and Community Services (DHCS) a licensed plumber can install the device without any installation approval.

2. greywater treatment systems (GTS) – the collection and treatment of greywater through an accredited greywater treatment system for reuse for non-potable uses. Once a GTS has been approved by the Department of Health and Community Services (DHCS) a licensed plumber can install the device after submitting a otification of installation to the DHCS.

Blackwater

As well as being generated at the household scale, blackwater may be captured at regional scales, from sewer mains, pumping stations or sewage treatment plants. In Darwin, treated wastewater is currently being reused at Darwin Golf Course and Marrara sports complex from treated wastewater transferred from Leanyer waste stabilisation ponds to a recycled water plant.

Water extracted from sewers is of variable quality and is highly contaminated. Contaminants include high total suspended solids, high biological oxygen demand, high levels of micro-organisms and high nutrients (total nitrogen and total phosphorus). How the water is used will dictate quality and treatment requirements. Typically, high water quality is required for water used for non-potable residential reuse and irrigation where public access can’t be controlled. Blackwater treatment typically includes screening, sedimentation, biological treatment, filtration and disinfection. Natural treatment systems can also be employed; sub-surface flow wetlands are designed for wastewater treatment.

Because the treatment of blackwater can be either energy or space intensive, it is pertinent to consider Ecologically Sustainable Development objectives when choosing the right treatment option for a particular site.

2.3.1 Location

Greywater is typically available only on individual sites where source separation of greywater and blackwater are possible. This limits its applicability as an alternative water source, except on small scales.

Blackwater is available throughout the sewerage network. Sewer flow peaks in the morning and evening, in line with people's everyday activities. As a sewer system increases in size, variation in flow is reduced. While blackwater requires more treatment than stormwater or greywater before it can be reused, there can be significant benefits in its predictability. The supply of a reliable quantity of water depends on the available source and upstream network. Smaller collection systems have greater sensitivity to flow variation. The advantage of a smaller upstream collection network is more certainty of supply quality. Potentially hazardous consumers such as industrial and other trade waste customers can be avoided by carefully selecting sewer extraction points.

Wastewater treatment systems can be applied at a range of scales, from individual lots to large regional systems. Some typical types of systems include:

- Greywater diversion and/or treatment on individual lots.
- Greywater and/or wastewater treatment in subdivisions or multi-storey buildings.
- Local wastewater treatment plants at a dub-division scale
- Water mining, harvesting wastewater from sewers.
- Wastewater reclamation, recovering treated effluent from regional wastewater treatment plants.

2.3.2 Design considerations

With the exception of some lot-scale greywater reuse systems, such as manual bucketing and subsurface irrigation, all greywater and wastewater reuse systems require water treatment before reuse can take place.

Design considerations for treatment systems include:

- Type of wastewater to be treated (greywater/blackwater).
- Water quality required for the reuse application.
- Flow rates to be treated and available space for treatment.
- The treatment process, including:
    - Pre-treatment including screening and solids separation
    - Biological treatment to remove nitrogen, suspended solids and organic matter.
    - Clarification/filtration to remove additional suspended solids and produce a high-clarity effluent that can be effectively disinfected.
    - Disinfection to inactivate pathogens.
- Energy requirements.
- Chemical inputs.
- By-products.
- Costs.

A number of different treatment options are outlined in Table 8.

Table 8: Wastewater treatment options

Biological treatment: suspended growth systems	Suspended growth systems use micro-organisms freely suspended in water to oxidise organic and ammonium nitrogen (to nitrate), decrease suspended solids and to some extent, reduce pathogen concentrations. These systems require oxygen input (usually with aerators), and produce sludge as a by-product. Suspended growth systems are good for blackwater treatment (they require a minimum nutrient level, therefore work less effectively for greywater). Process types include activated sludge and Sequencing Batch Reactors. These systems are typically used in large regional wastewater treatment plants.
Biological treatment: fixed growth systems	Fixed growth systems include trickling filters and rotating biological contactors. In trickling filters, wastewater is passed over a bed of media, where a biological film grows on the media's surface. Rotating biological contactors are made up of rotating discs which are passed through the wastewater. Both systems are aerobic, but oxygen can be provided by natural aeration, reducing energy needs. Sludge is a by-product. Fixed growth systems are similar to suspended growth systems in that they are more suited to blackwater than greywater. They are suited to small-medium scale applications such as wastewater treatment plants in high-rise buildings.
Biological treatment: Recirculating media filters	Recirculating media filters can be made up of sand or textile. They are similar to trickling filters, but can be applied on smaller scales, suitable for decentralised treatment. After passing through the filter, 80% of the filtrate is pumped back through the filter again. Recirculating media filters can be suitable for greywater as well as wastewater treatment and have a small footprint.
Media filters (sand and depth filtration)	Filtration is normally required after biological treatment to remove residual suspended solids and organic matter, which will ensure more effective disinfection. Sand and depth filters both use a granular filter media, through which effluent is passed. Media filter remove pollutants through the processes of straining, sedimentation and chemical adsorption.
Membrane filters	Membrane filters are available in four types: micro-filtration (with the largest pore size), ultra-filtration, nano-filtration and reverse osmosis (with the smallest pore size). Suspended solids, micro-organisms, natural organic matter and salts are filtered, depending on the pore size of the membranes. Smaller pore sizes can remove more pollutants but require greater energy inputs and higher pressure. Membrane filtration is suitable at a range of scales and is suitable for wastewater or greywater treatment. A concentrated waste stream is produced, typically around 15% of the total inflow. Membranes require regular cleaning and periodic replacement.
Membrane bioreactors	Membrane bioreactors combine biological treatment (suspended growth) with membrane filtration. The membranes can either be submerged in the bioreactor or can be a separate unit. These systems have relatively small footprints and produce high-quality effluent. They are suitable for greywater or blackwater treatment.
Subsurface flow wetlands	In subsurface flow wetlands, wastewater is treated in the soil media of a wetland. Plants play a role in biological decomposition. Subsurface flow wetlands can be used to remove organic matter and suspended solids from wastewater and greywater. They are relatively low cost and have low energy requirements. They have higher area requirements than other treatment systems. Wetlands can also be integrated into a landscape feature within a development.

Wastewater reuse applications generally require treated wastewater is disinfected before reuse. Three main disinfection options exist:

1. UV disinfection: UV light is used to irradiate pathogens. UV is reliable and relatively low-maintenance and is particularly suited to small-scale applications. No chemicals are needed and the process can be operated over a range of temperatures and pH levels. Energy inputs should be considered.

2. Chlorine is commonly used in large scale wastewater treatment plants and potable water supply systems. It provides both disinfection and residual microbial control. Chlorine disinfection is usually more suitable at larger scales because it requires pH adjustment, chemical storage, dosing system, and monitoring of the residual.

3. Ozonation is a third option, used less often. Specialised ozonation equipment is required, as well as energy inputs.

2.3.3 Maintenance

All wastewater treatment systems have regular maintenance requirements. Some require chemical and other inputs and most produce various by-products, such as sludge, which need to be managed. All treatment systems require some pumping and other energy inputs, and mechanical equipment would need to be maintained. Water quality monitoring would also be required for all systems.

2.3.4 Further Information

The DHCS has produced two information bulletins on the approval process for greywater reuse, which are available online:

- http://www.nt.gov.au/health/docs/cdc_envhealth_no1_manual_bucketing_temp_diversion_greywater.pdf

- http://www.nt.gov.au/health/docs/cdc_envhealth_no2_greywaterinfobulletin.pdf

Power and Water Corporation provide reclaimed water for various schemes and follow the National Water Quality Management Strategy, GUIDELINES FOR SEWERAGE SYSTEMS, Use of Reclaimed Water, November 2000 (ARMCANZ, ANZECC & NHMRC) for reclaimed water performance assessment and management. Reclaimed water systems in the NT will be treated on a case by case basis through the DHCS. More information can be found in a customer information bulletin which is available online at: http://www.powerwater.com.au/powerwater/business/connectioncode/pdfs_docs/customer_handouts/customer_handout_9.pdf

In addition, the Natural Resource Ministerial Council and Environment Protection and Heritage Council's *National Guidelines for Water Recycling* (draft 2005) provide a broad set of guidelines at national level.

A useful reference on wastewater treatment technologies is Landcom's document *Wastewater reuse in the Urban Environment: selection of technologies* (2006), available online: http://www.landcom.com.au/Wastewaterreuse.aspx.

2.4 Stormwater Harvesting, Storage and Reuse

Stormwater flows in the urban environment are higher, more frequent and of lower quality than in undeveloped catchments, which leads to negative impacts on downstream waterways. Harvesting stormwater flows from a catchment can therefore lead to benefits for downstream waterways by removing some of the excess stormwater flows as well as some of the pollutant load.

Stormwater harvesting reduces potable water demands and by reducing runoff volumes, also reduces pollutant loads. Stormwater harvesting, storage and reuse can also be an important tool for meeting hydrology objectives for developments upstream of important aquatic ecosystems including wetlands, lagoons, streams, mangroves and salt marsh.

2.4.1 Location

Stormwater harvesting schemes are located most appropriately at the downstream end of a stormwater catchment, close to the location where stormwater will be reused. Stormwater can be harvested from a pipe, culvert or open channel. It must then be treated before storage and reuse. Uses for treated stormwater may include indoor non-potable use, irrigation of public open space and other areas, industrial and commercial uses, e.g. for washdown, cooling tower make-up or process water and ornamental ponds and water features. Storage in Darwin can take the place of either storage ponds, storage tanks (Figure 3) or aquifer storage and recovery (ASR). Aquifer storage involves the pumping of water into a groundwater aquifer during the wet season and recovering the water for use during the dry season. ASR can be a low cost option for storage of water and also eliminates the loss of water from storages to evaporation during the dry season in Darwin. However aquifer storage will not be a viable option in the entire Darwin region, and the feasibility of ASR depends significantly on the underlying geology and the nature of the aquifers.

Figure 3: Stormwater storage being installed at the South Australian Museum (left), and stormwater harvesting pond at Barra Brui oval, St Ives (right)

2.4.2 Design considerations

In designing a stormwater harvesting scheme in Darwin, some of the key considerations are:

- Matching supply with demand, and in particular if stormwater is to be reused for irrigation deciding how to store water during the wet season to meet seasonal irrigation demands during the dry season. Stormwater can provide significant volumes of water for reuse, but supply is highly seasonal and a large storage may be required if the stormwater is only reused for seasonal irrigation demands.
- Quality requirements of the intended application. Stormwater can be treated for reuse using the same kind of treatment measures as outlined in Section 3. Depending on the reuse application, disinfection may also be required.
- Space available for treatment and storage. Large above-ground storages may require special safety considerations, such as dam safety.
- Underlying geology and assessment of an aquifers suitability for injection in an ASR scheme. Aquifers that contain confined sand and gravel aquifers and fractured unconfined rock are mostly likely to be suitable.
- Potential recovery rates of any suitable storage aquifers
- Water quality of the existing aquifer to ensure that it is suitable for reuse (e.g. ensuring that TDS levels are suitable)

- Pumping requirements, particularly for ASR injection scheme.

- Normally stormwater should be harvested from urban drainage systems. Where stormwater is harvested from a creek, geomorphology and aquatic habitat impacts should be minimised. If stormwater is harvested from a river, a water access licence may be required.

- Possibility to achieve reduced stormwater quantity and improving stormwater quality discharging from the catchment, i.e. meet multiple objectives.

- Potential health risks from pathogens in stormwater.

- Costs of stormwater harvesting, relative to other options.

The following sections outline key considerations associated with stormwater treatment for reuse, storage system sizing and open stormwater storage ponds.

2.4.2.1 Stormwater treatment

Stormwater treatment for storage and reuse should aim to remove gross pollutants and suspended solids as a minimum, so that these do not accumulate in the storage or interfere with the operation of pumps and the stormwater distribution system.

Where stormwater is to be stored in aquifers existing water quality should be monitored before injection to ensure that the quality of treated water does not degrade the groundwater quality. Treatment is also required in ASR to ensure that clogging of the aquifer does not occur. Where stormwater is to be stored above-ground, nutrient removal would also be important to minimise the risk of eutrophication and algal growth.

Depending on the application for treated stormwater, it may also be necessary to remove other pollutants such as salts, heavy metals and pesticides. Generally, where there is a possibility of public contact with treated stormwater (for example, in a sprinkler irrigation system at a sports field), disinfection is required.). Disinfection may be undertaken by chlorination, ozone or UV.

2.4.2.2 Stormwater storage sizing

Two different types of stormwater storages may be used as part of a stormwater harvesting and reuse scheme:

1. Stormwater storages sized to meet water demands, similar to a rainwater tank.

2. Aquifer storages with wet season injection rates based on equivalent water extraction demands from an aquifer during the dry season. In some cases ASR may require a buffer storage to ensure that sufficient volumes of treated stormwater are injected.

For any stormwater storage water balance modelling (for e.g. MUSIC) should be used to size an appropriate storage for reuse, based on supply and demand characteristics. A typical residential Greenfield development of 10 hectares, with 2 hectares of open space, has been modelled in MUSIC. To irrigate the public open space it was estimated that the demand for irrigation during the dry season was 10 ML/yr. Various storage sizes were modelled and the results are shown in Figure 4. The results show that a storage size of 2ML will supply approximately 75% of the irrigation demand. Hence a 2ML storage will provide water from the end of the dry season until the middle of September during a normal dry season, and potable water will be required for irrigation for the remaining months of the dry season.

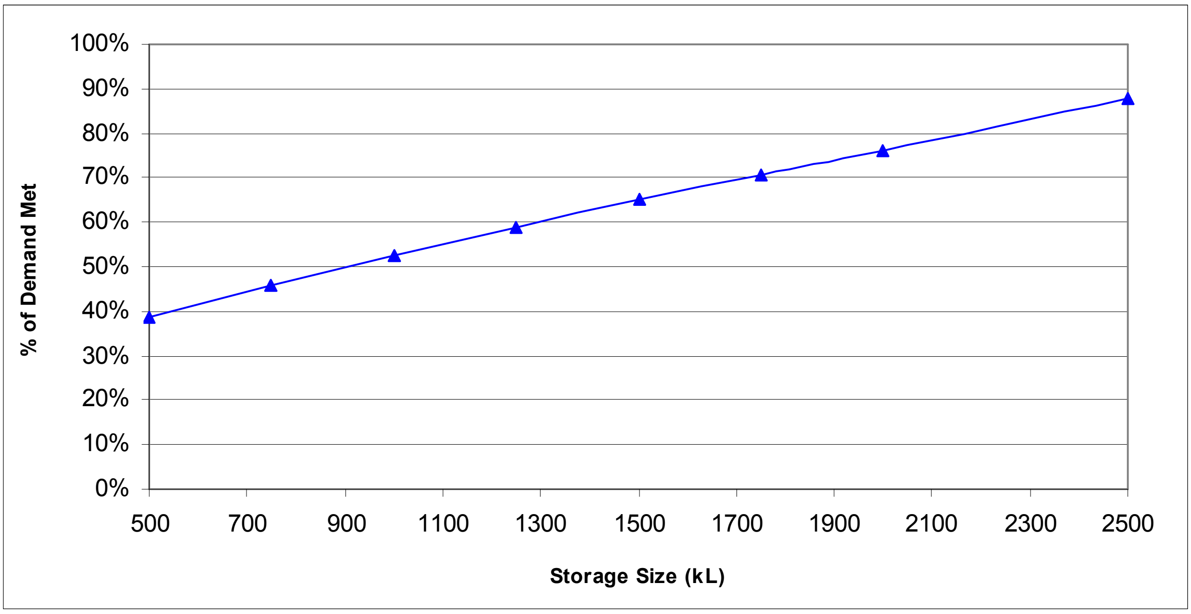


Figure 4: Storage sizing curve for a typical Greenfield residential development

There are trade-offs between the storage size and its reliability in meeting water demands. Stormwater harvesting is better able to meet demands that are spread evenly throughout the year, rather than irrigation demands which are seasonally dependent, however this typically requires plumbing back into buildings which has an extra cost for dual reticulation.

Aquifer stormwater storage

The general principle of aquifer storage and recovery is that as a minimum the equivalent of water that is to be extracted from the aquifer for reuse is to be injected into the aquifer. During the planning phase water balance modelling is required to determine the volumes of water that can be injected into the aquifer, and this should be monitored once the system is operation, Extraction of groundwater for reuse should not exceed the amounts that are injected.

ASR often requires use of a buffer storage which is rapidly drawn down with a pump injecting water into an aquifer at the end of a storm event. Buffer storages should typically be drawn down within a day in Darwin, to ensure that the storage volume is available within a short period after each storm event. This is in contrast with stormwater reuse storages, which are designed to retain water, so it is available to meet demands between storm events. The buffer storage size is determined by the inflows and the pump rate (or gravity feed rate) into the aquifer. Water balance modelling is required to determine the required size of the storage. The buffer storage can be integrated into a treatment system.

In the Darwin region, aquifer recharge may be limited by the storage volume of the aquifer rather than the natural infiltration into the aquifer during the wet season. In these cases aquifer recharge may not be required for use of groundwater from the aquifer. However, extractions from the aquifer water levels in the aquifer must be monitored to confirm that extraction is not depleting the aquifer.

2.4.2.3 Open stormwater storage ponds

Stormwater can be stored in open water bodies, and open stormwater storage ponds have aesthetic, recreational and habitat value. However, large bodies of open water are susceptible to algal blooms. To minimise the risk of algal blooms in open water bodies, a key design consideration is the "sustainable size". Two different considerations apply to the determination of a sustainable pond size:

1. **Hydrologic sustainability**: This is an assessment of the ability of the catchment to provide sufficient water to maintain adequate water levels in the pond throughout the dry season. The analysis needs to consider :

    - extraction of water for reuse
    - loss of water from the pond through evaporation

2. **Ecological sustainability**: The ability of a pond system to provide for a healthy ecosystem is largely determined by the concentrations of nutrients in inflowing water, and the residence time of that water in the water body. Excessive algal growth is a significant threat to an open water body, however algal growth can be managed by keeping residence times low enough to reduce the risk of eutrophication. The maximum sustainable residence time can be determined through water quality modelling, considering nutrient availability, light, temperature and hydrologic conditions. This is a key risk for Darwin due to long residence times in dry season and it is likely that any open water storage will need to manage residence times through recirculation through a wetland or similar.

Storage ponds are challenging to implement in the Darwin region due to the long dry season, high evaporation rates and correspondingly high irrigation demands. Hence a key design factor in Darwin is the large water level variation in an open storage pond. Open storages in Darwin will need to carefully consider:

- edge treatment due to drawdown in the dry season (Figure 5 shows two examples of ponds with different edge treatments) and
- the need to maintain a permanent pool throughout the year

It is likely that any pond storage will need to be more than 2m deep in total with 1m available for reuse and more than 1m for the depth of the permanent pool. These large water level variations and the careful consideration of edge treatment are crucial to the success of storage ponds in Darwin.

Other design considerations for stormwater storage ponds include:

- Public access and safety. Vegetation is typically incorporated around the pond edges to limit public access and improve safety (Figure 5).
- Inlet, outlet and overflow structures need to be provided to convey water to and from the pond and prevent scour and erosion.
- Soil investigations should be carried out before any major excavations, and ponds should be lined to prevent infiltration and ponds should not impede natural groundwater flows.
- Where a pond size larger than the sustainable size is desired, recirculation between a pond and a treatment wetland could be incorporated with a pump system to increase the pond size while keeping the residence time within an acceptable period.

Figure 5: Ponds at All Nations Park, Northcote Victoria (left) and Cairnlea Estate, Victoria (right)

2.4.3 Maintenance

Preventative maintenance could be undertaken through catchment management, which would aim to minimise pollutant loads in stormwater before it is harvested.

Many of the maintenance tasks are common to all schemes and tasks include:

- Removing any blockages from diversion systems.
- Periodic sediment removal from any storage or buffer storage.
- Monitoring for algal blooms in open storage ponds.
- For any storage, injection or reuse pump, mechanical equipment would need to be maintained.
- Edge vegetation will require weeding and some replanting.
- Storages should be monitored for scour and build-up of debris. Litter removal may be required.
- Occasionally it may be necessary to drain the permanent pond for corrective maintenance.
- Disinfection systems should be maintained according to manufacturers' advice.
- Distribution systems should be checked for leaks, faults, etc.
- Where stormwater is used for irrigation, irrigated areas should be checked for erosion, under-watering, waterlogging or excess surface runoff.

2.4.4 Further Information

National guidelines for stormwater harvesting and reuse and ASR which focus on managing the environment and health risks of stormwater reuse are available online at: http://www.ephc.gov.au/ephc/water_recycling.html

Australian guidelines have been developed for aquifer storage and recovery, based on the experience of ASR in South Australia. For example the EPA SA (Environment Protection Authority South Australia) 2004, Code of Practice and Recovery, EPA SA is a good resource on ASR and it is available online at: http://www.environment.sa.gov.au/epa/pdfs/cop_aquifer.pdf

Licensing of groundwater bores is the responsibility of Natural Resources, Environment and the Arts and more information on the regulatory process for ASR can be found online at http://www.nt.gov.au/nreta/water/ground/services/index.html

3 Stormwater quality

Stormwater is runoff from ground surfaces such as roads, carparks and pedestrian areas. Stormwater can contain gross pollutants, sediments, nutrients, heavy metals, hydrocarbons and faecal contamination. No single treatment measure can effectively treat this full range of pollutants. The design of most stormwater pollutant removal processes mean that only some pollutants can be targeted. A combination of treatments is required to remove a high proportion of stormwater pollutants.

A series of treatment measures that collectively address a range of stormwater pollutants is called a “treatment train”. The selection and order of treatments is vital to the effectiveness of a treatment train. Coarser pollutants generally require removal early in the treatment train, so that treatments that target fine pollutants can operate more effectively. The proximity of a treatment to its source is another factor to consider, as is the distribution of treatment systems throughout a catchment.

Table 4 lists some basic information to assist in selection of appropriate treatment measures. Further information on these measures is included in Sections 3.1 to 3.5.

Table 4: Application of typical stormwater quality treatment measures

Treatment measure	Potential applications	Suitable site conditions	Unsuitable site conditions
Vegetated swales	Medium and fine particulate removal, including phosphorus removal Streetscape amenity Wildlife habitat	Mild slopes	Steep terrain
Buffer strips	Pre-treatment of runoff for sediment removal Streetscape amenity	Flat and gently sloping terrain	Steep terrain
Bioretention systems	Fine and soluble pollutants removal, including nitrogen and phosphorus Streetscape amenity Frequent flood retardation Wildlife habitat	Flat and gently sloping terrain	Steep terrain High groundwater table
Sand filters	Medium and fine particulate removal, including phosphorus removal Rapid filtration prior to storage and reuse	Constrained areas Underground systems	
Sediment basins	Coarse sediment capture Temporary installation Pre-treatment for other measures	Need available land area	
Wetlands	Community asset Medium to fine particulate and soluble pollutant removal, including nitrogen and phosphorus Flood retardation Storage for reuse Wildlife habitat	Flat and gently sloping terrain	Steep terrain High groundwater table Acid sulphate soil
Gross pollutant traps (GPTs)	Reduces litter and debris, including organic matter Can reduce sediment Pre-treatment for other measures	Conventional drainage systems	Catchments larger than 100 ha Natural channels
Infiltration systems	Reduces surface flows Groundwater recharge	Soils with high permeability	Shallow bedrock, shallow groundwater, low permeability soils

Treatment measure selection is influenced by site conditions and the characteristics of the target pollutants. Figure 6 and Figure 7 are a guide to appropriate treatment measures for different pollutant types.

Stormwater treatment measures that target the removal of gross pollutants and coarse sediment (including gross pollutant traps and sedimentation basins) can operate under high flowrates. A relatively small device can effectively treat a large catchment area.

Treatments for smaller pollutant particles (including nutrients and metals) can include swales, wetlands and bioretention systems. These treatments use vegetation to provide filtration, spread flows and reduce velocities. Vegetation enhances sedimentation and also provides a substrate for biofilm growth and biological uptake of soluble pollutants. Bioretention systems also use a filter media (e.g. sandy loam) to provide further filtration. Media filtration further slows velocities. Grass swales, vegetated buffer strips, wetlands and bioretention systems take longer than gross pollutant traps to remove pollutants, and a larger area is required for the same catchment. Therefore a larger land area is required to remove small particles than large ones from stormwater.

Particle classification and size (µm)	Common stormwater pollutant types				
	Visual	**Sediment**	**Organics**	**Nutrients**	**Metals**
Gross solids >5000 µm	↑ Litter	↑ Gravel	↑ Plant		
Coarse to medium 5000 - 125 µm			debris		↑
Fine particulates 125 - 10 µm		Silt ↓		↑ Particulate	Particulate
Very fine/colloidal 10 - 0.45 µm	Turbidity ↓		Natural & anthropogenic		Colloidal ↓
Dissolved particulates <0.45 µm			materials ↓	Soluble ↓	

Figure 6: Size range of typical stormwater pollutants
(Adapted from Ecological Engineering (2003) Landcom Water Sensitive Urban Design Strategy - Design Philosophy and Case Study Report, report prepared for Landcom, NSW)

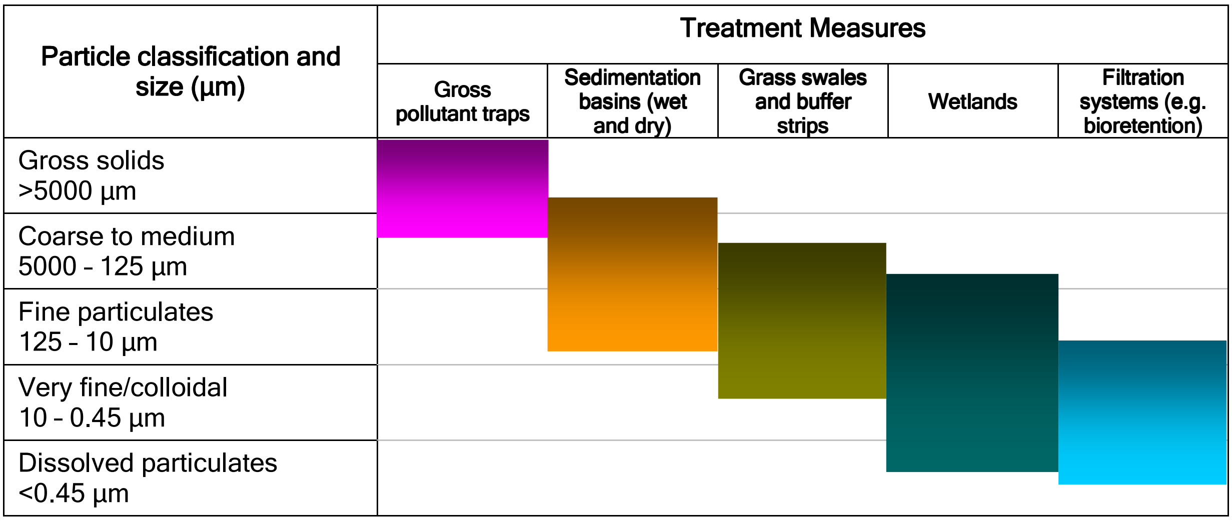


Figure 7: Treatment options for different size ranges
(Adapted from Ecological Engineering (2003) Landcom Water Sensitive Urban Design Strategy - Design Philosophy and Case Study Report, report prepared for Landcom, NSW)

Design of WSUD elements needs to consider the full range of conditions under which WSUD elements must operate. The performance of an urban stormwater quality improvement strategy is measured through the impact of a continuous period of typical climatic conditions. Computer modelling, as described in the "Stormwater Quality Modelling Guide" document, is used to predict system performance in terms of mean annual pollutant loads captured.

Sizing curves provided in this document can provide a useful first estimate of treatment measure performance before detailed modelling is undertaken. Detailed modelling will be necessary on all projects to predict treatment performance more reliably. The sizing curves can then also be used to check that model results are within the expected range.

3.1 Vegetated Swales and Buffer Strips

Vegetated swales are used to convey stormwater in lieu of, or with, underground pipe drainage systems. Vegetated swales are both a stormwater conveyance and treatment mechanism. They are effective for removal of suspended solids, particularly coarse sediments, and will also reduce some phosphorus and nitrogen loads. They are commonly combined with buffer strips and bioretention systems, or may be used as a pre-treatment measure upstream of a wetland. Swales utilise overland flow and mild slopes to convey water slowly downstream. They provide a means of disconnecting impervious areas from downstream waterways, assisting in protecting waterways from damage by frequent storm events, by reducing flow velocity compared with piped systems.

The interaction between stormwater flow and vegetation within swale systems facilitates pollutant settlement and retention. Even swales with relatively low vegetation height (such as mown grass) can achieve significant sediment deposition rates provided flows are well distributed across the full width of the swale and the longitudinal grade of the swale is kept reasonably low (typically less than 4 % grade) to maintain slower flow conditions.

Swales alone cannot provide sufficient treatment to meet current best practice stormwater treatment/water quality objectives, but can provide an important pretreatment function for other WSUD measures in a treatment train, enabling water quality objectives to be met. Swales are particularly good at coarse sediment removal as a pretreatment for wetlands and bioretention systems.

Buffer strips (or buffers) are areas of vegetation through which runoff passes while travelling to a discharge point. They reduce sediment loads by passing a shallow depth of flow through vegetation and rely upon well distributed sheet flow. Vegetation tends to slow velocities and coarse sediments are retained.

3.1.1 Location

Vegetated swales can be used instead of pipes to convey stormwater and provide a 'buffer' between the receiving water and the impervious areas of a catchment. They could be integrated with landscape features in parks and gardens. As shown in Figure 8, swales can be incorporated in street designs and add to the aesthetic character of an area.

Buffer strips are intended to slow and filter flow from impervious surfaces to the drainage system. The key to their operation, like swales, is an even shallow flow over a wide vegetated area. The vegetation facilitates an even distribution and slowing of flow thus encouraging pollutant settlement. Vegetation also takes up some nutrients. Buffers are commonly used as a pre-treatment for other stormwater measures. With their requirement for uniformly distributed flow, buffer strips are suited to treatment of road runoff in situations where road runoff is discharged via flush kerbs or through regular kerb 'cut-outs'. In these situations, buffer strips can be located at the edge of a road, a carpark or a pedestrian area. Buffer strips are often incorporated on the outer edges of a swale, as in Figure 8.

Figure 8: Typical swale and buffer strip configuration

3.1.2 Design considerations

A typical swale configuration is shown in Figure 9. Swales are normally sized to convey low flows, for example the 3 month ARI peak flow, however they can also be sized for conveyance of higher flows where required. Typical widths range from 0 to 2.0 m at the base and side slopes are normally 1 in 3 to 1 in 6. Swales operate best with slopes from 2% to 4%. Slopes milder than this can tend to become waterlogged and have stagnant ponding, although the use of underdrains can alleviate this problem. For slopes steeper than 4%, check banks along swales, dense vegetation and/or drop structures can help to distribute flows evenly across the swales as well as slow velocities. Driveway crossovers can provide an opportunity for check dams (to provide temporary ponding) or can be constructed at grade and act like a ford during high flows (see Figure 10).

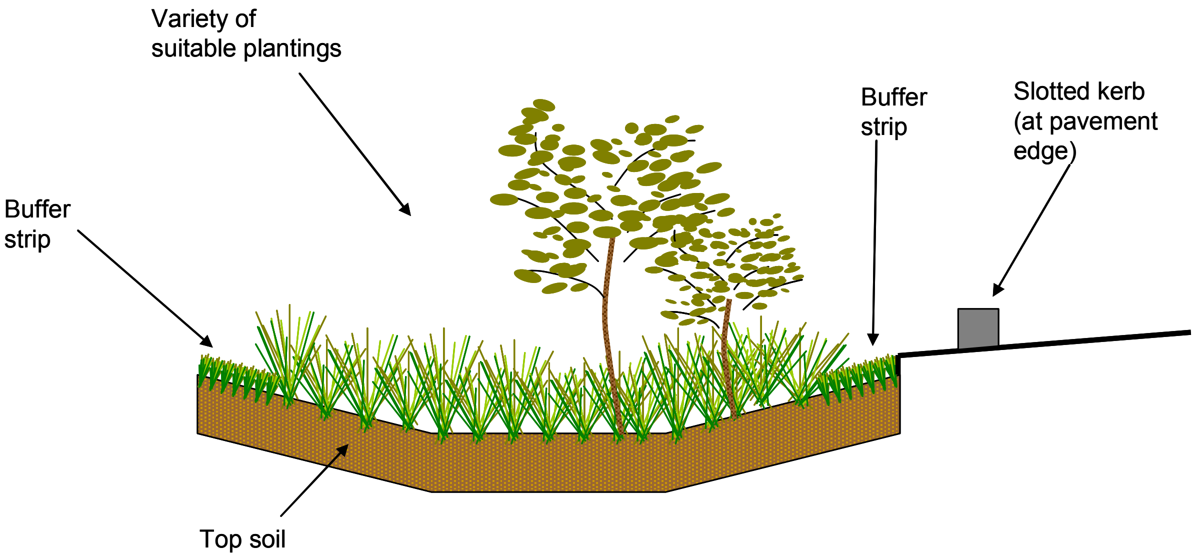


Figure 9: typical swale arrangement



Figure 10: Examples of different types of swale crossings

Buffer strips should be set down from the paved surface to account for sediment accumulation and plant growth over time (see Figure 11). Generally between 40 and 50 mm set down from the paved surface will be adequate with a pavement surface that is tapered down towards the buffer strip (as illustrated in Figure 11).

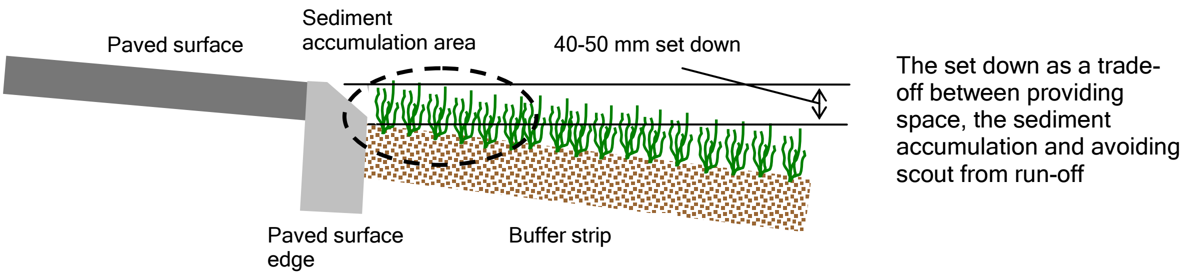


Figure 11: Typical buffer strip arrangement

Vegetation should cover the whole width of the swale, be capable of withstanding design flows and be of sufficient density to provide good filtration. It should also be selected to be compatible with the landscape of the area and maintenance capabilities. For best performance, vegetation height should be above the water level for the design flow.

Edge treatment should prevent vehicular access to roadside swales, and allow flows into the swale. Some examples of different arrangements for delivering water to a swale while restricting vehicular access are shown in Figure 12.

Figure 12: Different arrangements for delivering water to a swale and preventing vehicular access

Vegetation in swales is important to ensure the pollution reduction performance of the system. The planting densities should be high to provide maximum contact between stormwater and vegetation. The species selection should be guided by the local environment and flora of the region. A few options are possible:

- Swales can be turfed, however turf will not be able to withstand long dry periods unless the swale is appropriately irrigated.
- Denser vegetated swales with native grasses, sedges, shrubs and trees could be used. However native grasses tend to be sparse with low vegetation cover during the dry, and irrigation may still be worthwhile:
    - Sparse vegetation cover may compromise treatment performance at the start of the wet season. This could be overcome by irrigating the swale for a few weeks before the start of the wet season.
    - Sparse vegetation cover in the dry season may be inconsistent with urban design objectives. Native vegetation could be irrigated throughout the dry season to maintain its appearance.

Therefore irrigation may be a necessary component of swales in the Darwin region. Soil for the swale should be 300 mm deep of good quality loam topsoil to support the vegetation. Good quality topsoil will help minimise irrigation requirements.

3.1.3 Sizing

Swales may be sized for either conveyance or treatment of stormwater, as they have a dual function. Typically a swale would be sized to convey the 3-month to 1-year ARI peak flow. Where swales are used in place of pits and pipes, they should be sized for the standard design storm, as defined by the local council. Where swales are designed principally for water quality, they can include overflow pits to allow high flows into the piped drainage system, and this will minimise the size of the swale.

Sizing curves for swales are shown in Figure 13. The sizing curves plot the performance of swales according to their size as length per hectare of catchment area. The curves give an approximation of treatment performance, suitable for preliminary sizing.

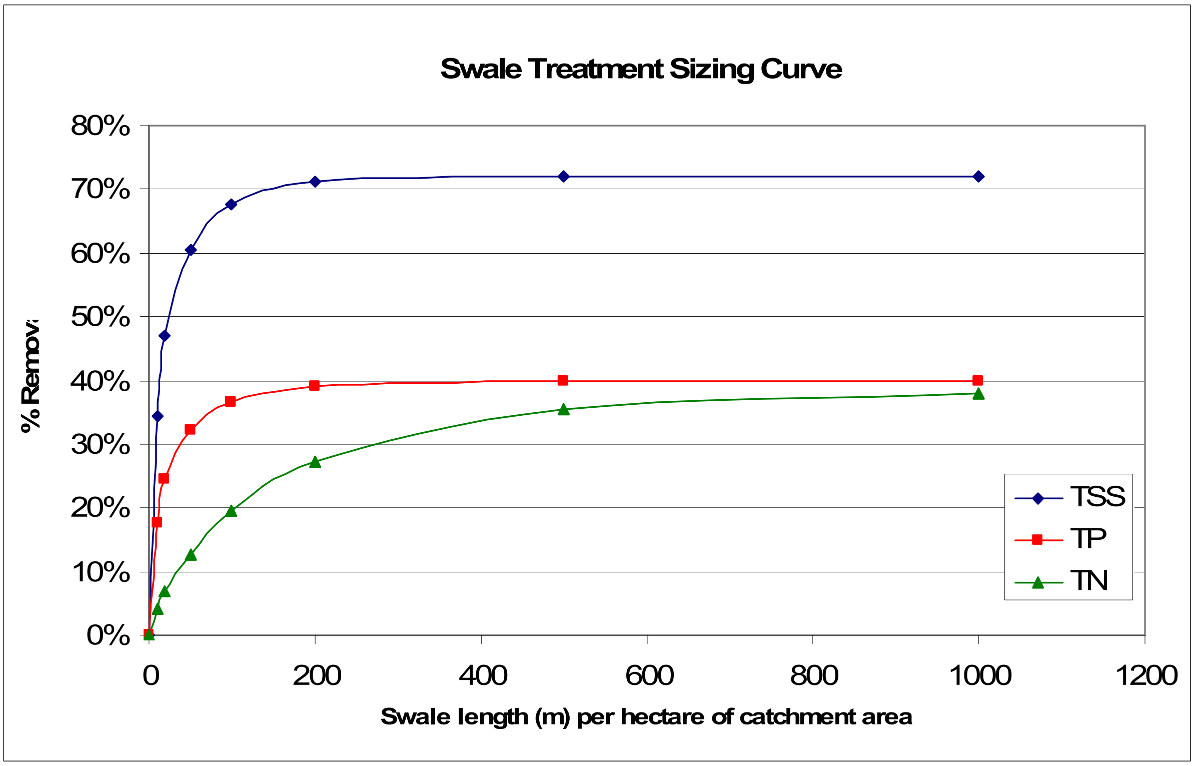


Figure 13: Swale preliminary sizing curve for the Darwin region

3.1.4 Maintenance

Maintenance for swales is typical of open landscaped gardens, with vegetation growth the key objective. This is because the vegetation in swales provides most of the pollutant removal. Good vegetative growth is the key maintenance objective since the vegetation in swales supports the pollutant removal. Typical maintenance requirements for swales include:

- Monitoring for scour and erosion, and sediment or litter build-up
- Weed removal and plant re-establishment
- Monitoring overflow pits for structural integrity and blockage

3.1.5 Further Information

Information on modelling swales in MUSIC is included in the "Stormwater Quality Modelling Guide".

For more detailed information on swales and buffer strips refer to:

- The *Water Sensitive Urban Design Technical Design Guidelines for Southeast Queensland* (Moreton Bay Waterways and Catchments Partnership, 2006), available online at http://www.healthywaterways.org/wsud_technical_design_guidelines.html.
- The "WSUD Stormwater Treatment Options for Darwin" Discussion Paper (EDAW, 2007).

3.2 Bioretention systems

Bioretention systems can be configured as basins (or rain gardens), planter boxes, street trees, or in the base of swales. Bioretention systems are vegetated areas where runoff is filtered through a filter media layer (e.g. sandy loam) as it percolates downwards. It is then collected in a drainage layer via perforated under-drains and flows to downstream waterways or to storages for reuse. Bioretention basins typically use temporary ponding of 0.2–0.4 m depth above the filter media surface to increase the volume of runoff treated through the filter media. Flows above the design flow are conveyed through overflow pits or bypass paths. This has the advantage of protecting the filter media surface from high velocities that can dislodge collected pollutants or scour vegetation.

Vegetation plays a key role in bioretention systems. The surface is densely planted with ground level grasses and rushes and may also contain selected tree and shrub species. The agitation of the surface of the bioretention basin caused by movement of the vegetation and the growth and die off of root systems prevents accreted sediments clogging the filtration media. Beneath the surface, vegetation provides a substrate for biofilm growth within the upper layer of the filter media. Vegetation facilitates the transport of oxygen to the soil and enhances soil microbial communities which enhance biological transformation of pollutants.

Bioretention basins are generally not intended to be 'infiltration' systems that discharge from the filter media to surrounding in-situ soils. Rather, the typical design intent is to recover stormwater at the base of the filter media in perforated under-drains and discharge to receiving waterways or to storages for potential reuse. In some circumstances however, where the in-situ soils allow and there is a particular design intention to recharge local groundwater, it may be desirable to allow stormwater to infiltrate from the base of a filter media to underlying in-situ soils.

3.2.1 Location

Bioretention systems can be implemented in many sizes and shapes in a range of different locations. For example bioretention systems can be designed as planter boxes, in parks or in streetscapes integrated with traffic calming measures (Figure 14). It is important to have sufficient depth (normally at least 0.8 m) between the inlet and outlet, therefore they may not be suitable at sites with shallow bedrock or other depth constraints, however they are otherwise a very flexible and effective treatment measure for nutrients and suspended solids.

Figure 14: Examples of bioretention systems in planter boxes, in the streetscape, and in parks

3.2.2 Design considerations

A typical bioretention system configuration is shown in Figure 15. Key components include extended detention, filter media, drainage layer and overflow pit.

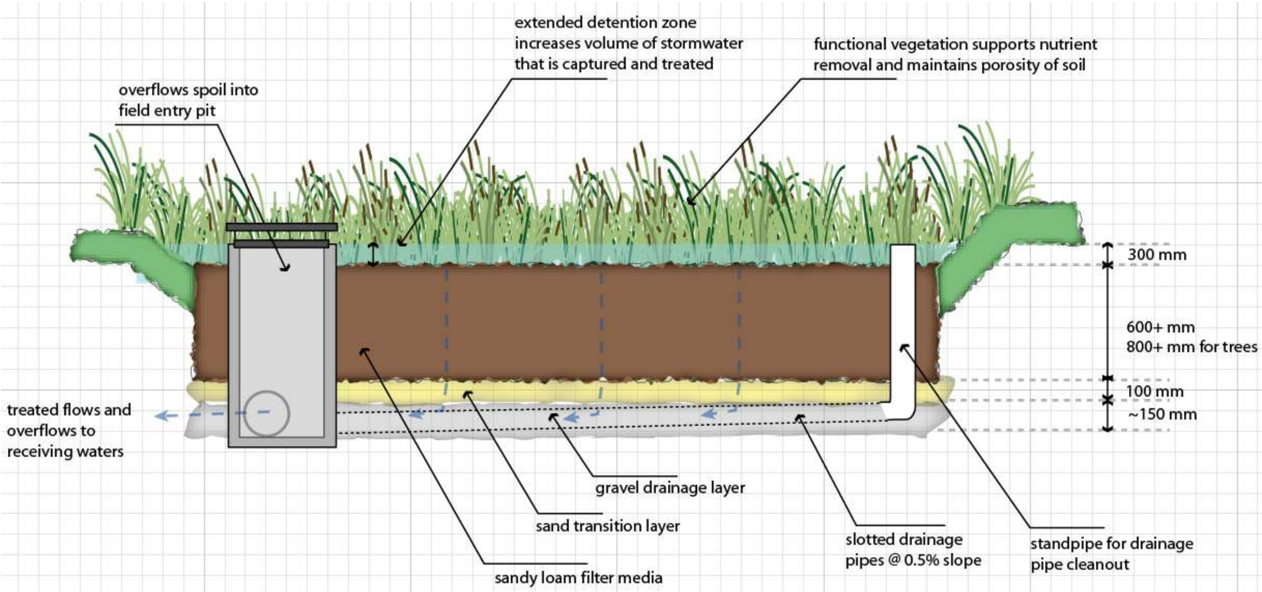


Figure 15: Biroetention system typical arrangement

Selection of an appropriate filtration media is a key issue that involves a trade-off between providing sufficiently high hydraulic conductivity to treat as much stormwater as possible, while retaining sufficient water to support vegetation growth. Normally sandy loam is recommended with a saturated hydraulic conductivity in the range of 100-200 mm/hr. Some organic matter is beneficial; however organic content should be kept to a low percentage to avoid leaching nutrients from the system. A detailed soil specification for bioretention systems is available from the Facility for Advancing Water Biofiltration (FAWB) at Monash University: http://www.monash.edu.au/fawb. Only soils that meet this specification should be used for bioretention systems.

Vegetation that grows in the filter media enhances its function by preventing erosion of the filter medium, continuously breaking up the soil through plant growth to prevent clogging of the system and providing biofilms on plant roots that pollutants can adsorb to.

Plants used in bioretention systems should be suited to sandy, free-draining soils, and tolerant of drought. Bioretention systems should be planted densely to maximise the biological processing of nutrients. Planting can incorporate several growth forms – shrubs, tufted plants and groundcover species, to ensure that the plant roots occupy all parts of the media. Using several species reduces the risk that insect attack, disease or adverse weather will harm all of the plants at once. Species should be consistent with the landscaping of the area.

Bioretention systems must be protected from clogging by pretreating stormwater to remove coarse to medium sediments. Pretreatment by sedimentation basin or swale is appropriate prior to directing stormwater to a bioretention system. A sediment forebay can also be included at the inlet to the bioretention system. If the filter media clogs, it will need to be replaced.

Typically flood flows bypass the device thereby preventing high flow velocities that can dislodge collected pollutants or scour vegetation.

Conventional bioretention systems could operate effectively in the Darwin Region, providing some key issues are addressed. Some design options include:

- Allowing bioretention vegetation to die back during the dry season, which will need to be carefully integrated with the urban design and aesthetics of the landscape. Suitable vegetation, such as savanna vegetation should be chosen that can survive the dry season without complete die-off.

- Irrigation of the bioretention system during the dry season. If shallow rooted perennial vegetation which cannot withstand the long dry season are used in the bioretention system and the vegetation is to be maintained during the dry season it will be necessary to irrigate the bioretention system. There are a number of advantages to maintaining the bioretention system vegetation via irrigation, including the ability to cope with sediment and pollutant loads during the first rain events at the beginning of the wet season, reduced risk of wind blown erosion, and landscaping and aesthetic reasons.

- The use of trees and shrubs which are adapted to tropical savanna conditions, in an un-lined bioretention system. Subject to site-specific considerations, such vegetation would be able to access groundwater during the dry season.

Alternatively, incorporating a saturated zone may be one way to overcome some of the issues associated with bioretention system drying. This option is discussed in the "WSUD Stormwater Treatment Options for Darwin" Discussion Paper (EDAW, 2007). These types of system are still at an experimental stage.

3.2.3 Sizing

Sizing curves for bioretention systems are shown in Figure 16. The sizing curves plot the performance of bioretention systems according to their size as a percentage of catchment area. The curves give an approximation of treatment performance, suitable for preliminary sizing.

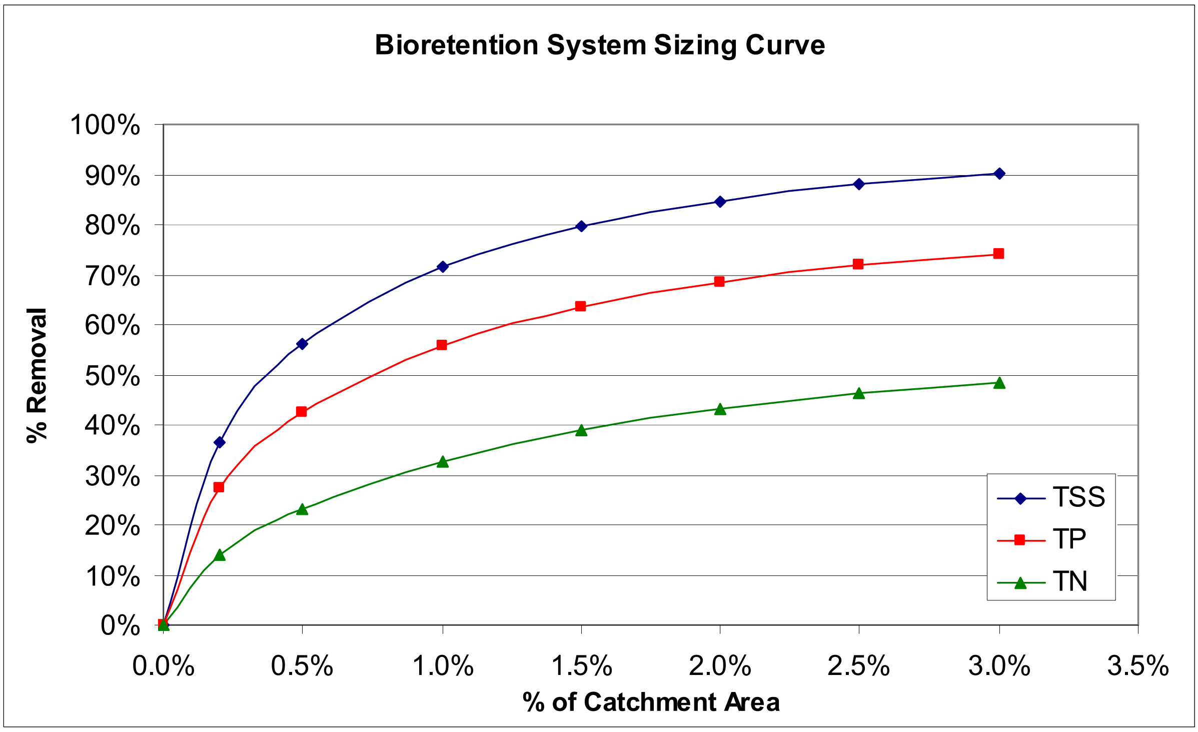


Figure 16: Bioretention system preliminary sizing curve for the Darwin region

3.2.4 Maintenance

Bioretention systems require regular maintenance, similar to swales. Maintenance requirements of bioretention systems include:

- Monitoring for scour and erosion, and sediment or litter build-up

- Weed removal and plant re-establishment
- Monitoring overflow pits for structural integrity and blockage

3.2.5 Further Information

Information on modelling bioretention systems in MUSIC is included in the “Stormwater Quality Modelling Guide”.

For more detailed information on bioretention systems strips refer to:

- The *Water Sensitive Urban Design Technical Design Guidelines for Southeast Queensland* (Moreton Bay Waterways and Catchments Partnership, 2006), available online at http://www.healthywaterways.org/wsud_technical_design_guidelines.html.
- The “WSUD Stormwater Treatment Options for Darwin” Discussion Paper (EDAW, 2007).

3.3 Wetlands

Wetlands are a common treatment measure used to treat stormwater runoff in temperate climates. Constructed wetland systems are shallow, extensively vegetated water bodies that use enhanced sedimentation, fine filtration and biological uptake processes to remove pollutants from stormwater. Water levels rise during rainfall events and outlets are configured to slowly release flows, typically over two to three days, back to dry weather water levels. In addition to treating stormwater, constructed wetlands can also provide habitat, passive recreation, improved landscape amenity and temporary storage of treated water for reuse schemes.

Constructed surface flow wetland systems remove pollutants in stormwater through sedimentation, fine filtration and biological uptake. The main components of a wetland are:

- An inlet zone (sedimentation basin to remove coarse sediments)
- A macrophyte zone (a shallow heavily vegetated area to remove fine particulates and take up soluble pollutants), and
- A high flow bypass channel (to protect the macrophyte zone from scour and vegetation damage).

Wetland systems can also incorporate open water areas. The pollution reduction processes in wetlands are engaged by slowly passing runoff through heavily vegetated areas where plants filter sediments and pollutants from the water. Biofilms that grow on the plants can absorb nutrients and other associated contaminants. While wetlands can play an important role in stormwater treatment, they can also have significant community benefits. They provide habitat for wildlife and a focus for recreation, such as walking paths and resting areas. They can also improve the aesthetics of new developments and can be a central landscape feature.

3.3.1 Location

Wetland systems can be combined with flood protection measures when incorporated into retarding basins. An open water body or pond at the downstream end of a wetland can provide water storage for reuse purposes, such as irrigation. Wetlands can be constructed on many scales, from small devices to large regional systems. In highly urban areas they can have a hard-edged form and be part of a streetscape or building forecourt. In regional settings they can be over 10 hectares in size and provide significant habitat for wildlife (Figure 17).

Figure 17: Small and large-scale wetlands (Docklands and Lynbrook in Melbourne)

3.3.2 Design considerations

A conceptual diagram of a constructed wetland is shown in Figure 18. The wetland is shown with a distinct wet season and dry season character. The wetland includes submerged marsh and shallow marsh zones. The inlet zone is not shown.

Effective pollutant removal in wetlands depends largely on the macrophytes in the shallow marsh zone. Vegetation in the macrophyte zone plays a key role in pollutant removal, and it is therefore important to protect vegetation from high flows, debris and high sediment loads. Open water zones can provide a polishing step, as UV light provides some disinfection. Some of these considerations are illustrated in Figure 19. Key design considerations are as follows:

- **Pre-treatment -** Pre-treatment of stormwater is necessary to protect wetland function. Gross pollutants and course to medium sediments should be removed before runoff reaches the wetland. A combination of a gross pollutant trap and a sediment basin are recommended.

- **Inlet zone and bypass structure -** The inlet zone or sediment basin reduces flow velocities and encourages settling of sediments from the water column. The inlet zone can drain during periods without rainfall and then fill during runoff events. The inlet zone is sized according to the design storm discharge and the target particle size for trapping. Typically it is about 15-30% of the total wetland area and around 2 m deep.

- **Macrophyte zone -** For macrophyte zones to function efficiently, flows that pass through the vegetation must be evenly distributed. Dense vegetation growth is required to dissipate flows and to support efficient filtration. Flow and water level variations and maximum velocities are important considerations and can be controlled with an appropriate outlet structure. Different zones in a macrophyte zone perform different functions. Ephemeral areas are organic matter traps. These areas wet and dry regularly and thus enhance the breakdown process of organic vegetation. Marsh areas promote epiphyte (biofilms) growth on the plant surfaces. Epiphytes promote adhesion of fine colloidal particulates to wetland vegetation and uptake of nutrients. The marsh plants remove nutrients and promote microbial activity.

- **Open water zone -** Sometimes, there are areas of open water surrounding the outlet of wetlands. These can increase UV disinfection and provide habitat for fish and other aquatic species, as well as perform an aesthetic and passive recreation function.

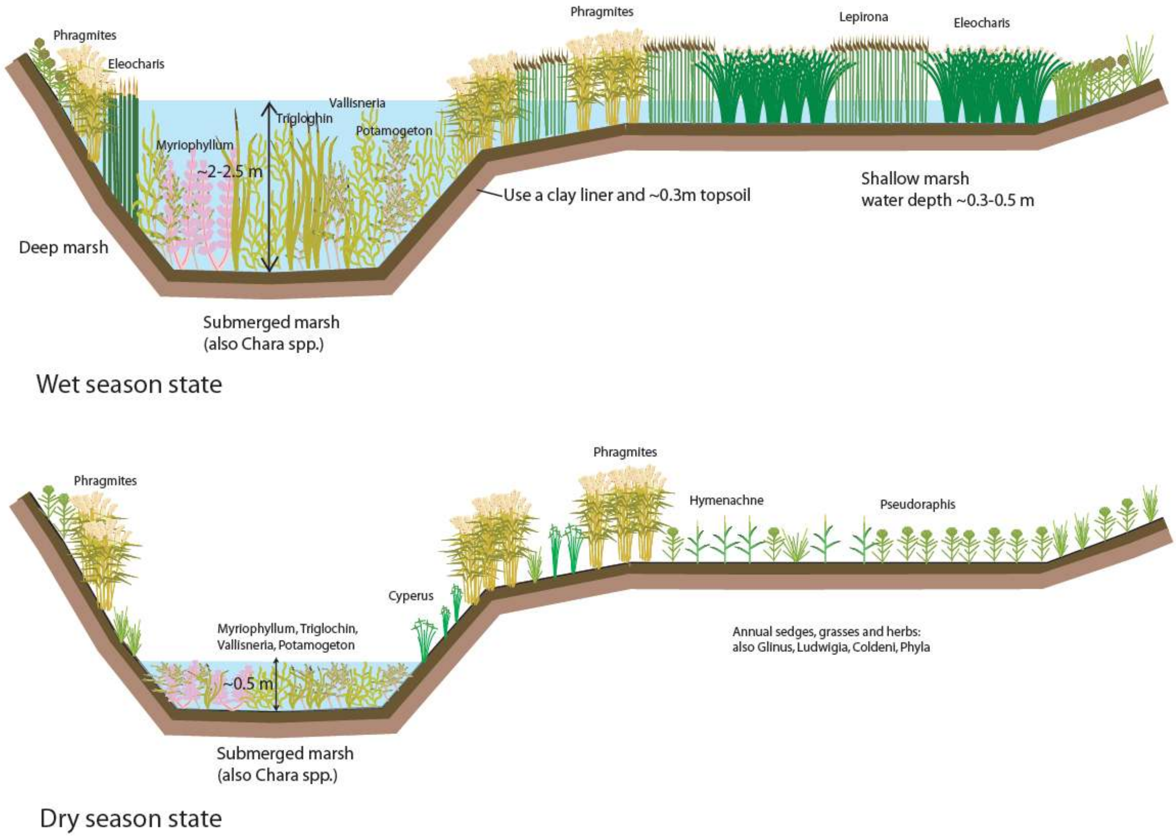


Figure 18: Conceptual diagram of a wetland

A high flow bypass is essential to protect vegetation

Vegetation provides a key pollutant removal role

Open water zones allow sunlight to provide some disinfection and provide habitat

Figure 19: Key wetland design considerations

Wetlands are usually designed with the detention time of 72 hours to ensure design performance. The macrophyte zone outlet orifice must be sized accordingly. Multiple level orifice riser outlets are considered to give the most uniform detention times for wetlands.

Wetlands can be designed to eliminate mosquito habitat, and to encourage mosquito predators. For more information please refer to the *Water Sensitive Urban Design Technical Design Guidelines for Southeast Queensland* (Moreton Bay Waterways and Catchments Partnership, 2006), available online at http://www.healthywaterways.org/wsud_technical_design_guidelines.html.

Vegetation for wetlands is important to ensure the pollution reduction performance of the system. A range of species should be selected according to their structure, hydrologic requirement, drought tolerance and growth form. The species selection should be guided by the environment and flora of the region. Soil for the wetland should be 300 mm deep of good quality loam topsoil to support the vegetation.

3.3.3 Sizing

Sizing curves for constructed wetlands are shown in Figure 20. The sizing curves plot the performance of constructed wetlands according to their size as a percentage of catchment area. The curves give an approximation of treatment performance, suitable for preliminary sizing.

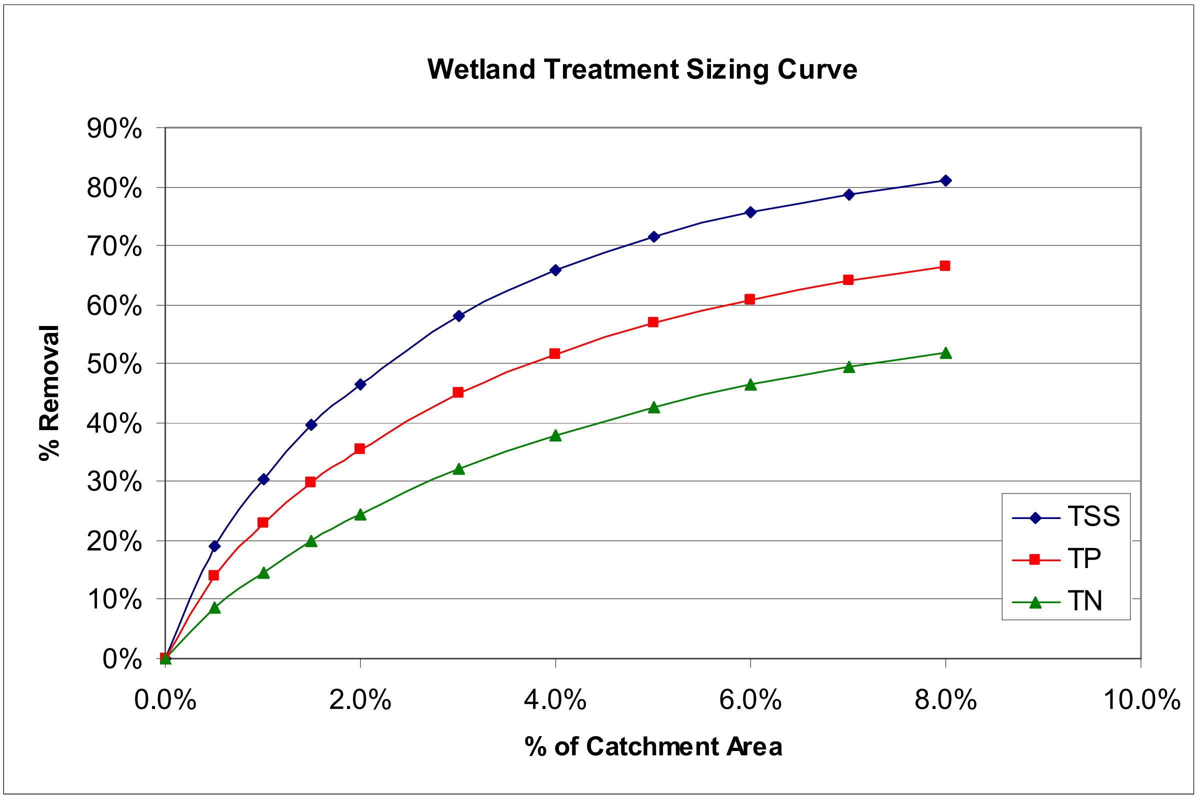


Figure 20: Wetland sizing curves for the Darwin region

3.3.4 Maintenance

Wetlands require the following routine maintenance activities:

- Checking the wetland after storms for scour and erosion
- Removing debris, particularly around inlets and outlets
- Regularly removing sediment from the sediment basin
- Weeding and replanting

It can be useful to design wetlands to allow them to be completely drained. This can assist in occasional corrective maintenance actions such as extensive weeding and replanting. This would also assist in the control of pests such as Gambusia, which can be removed from a waterbody by drying it out extensively, then refilling.

3.3.5 Further Information

Information on modelling wetlands in MUSIC is included in the "Stormwater Quality Modelling Guide".

For more detailed information on wetlands refer to:

- the *Water Sensitive Urban Design Technical Design Guidelines for Southeast Queensland* (Moreton Bay Waterways and Catchments Partnership, 2006), available online at http://www.healthywaterways.org/wsud_technical_design_guidelines.html.
- The "WSUD Stormwater Treatment Options for Darwin" Discussion Paper (EDAW, 2007).
- The DLWC *Constructed Wetlands Manual*, 1998.
- The CRC for Catchment Hydrology *Managing Urban Stormwater Using Constructed Wetlands* 1999.
- The Institute of Engineers *Australian Runoff Quality* 2006.

3.4 Gross Pollutant Traps

Gross pollutants include litter, leaves and other vegetative matter. Many gross pollutant traps (GPTs) will also capture significant loads of coarse suspended solids.

3.4.1 Location

GPTs are often the first treatment measure in a treatment train, for example they can be used upstream of wetlands and other water bodies to protect them from gross pollutants. Gross pollutant capture efficiency varies between different types of GPTs, as does coarse sediment removal. Most GPTs cannot remove fine sediments, nutrients or other pollutants to any significant degree.

GPTs are available in a range of different types and sizes, suitable for a wide range of applications. The range is outlined in Figure 31.

3.4.2 Design Considerations

Key design considerations include:

- The size of the catchment to be treated, and the flow rate that must pass through the GPT (see **Error! Reference source not found.** for the range of scales of GPTs). GPTs are normally sized to treat the 3-month to 1-year ARI flow.
- The type of waterway on which the GPT is to be installed (pipe/culvert/open channel).
- Pollutant types and loads in the catchment – for example, commercial areas are likely to generate higher loads of litter than residential areas.
- What sort of pollutants the GPT is designed to collect. For example, as pre-treatment to a wetland, it is important to remove coarse sediment loads. However at other locations, it may be undesirable to trap sediment, in case it reduces natural sediment deposition downstream.
- The GPT's efficiency in trapping pollutants will affect the frequency and magnitude of cleanouts, and the volume of waste material that must be disposed of.
- Some GPTs store captured pollutants in a drained state, while others hold them in stagnant water. Anaerobic conditions in wet sumps can lead to odours, and wet pollutants may be more difficult to clean out than dry pollutants.

- Access and equipment requirements for cleanouts. Small pit insert GPTs may be cleaned out by hand, while larger GPTs may require a bobcat, excavator or crane to remove the pollutants and/or basket.
- Upstream flooding. GPT designs should ensure that there is no risk of increased flooding upstream of the GPT.
- Costs. It is important to consider the life cycle costs of GPTs, as operation and maintenance costs over the lifetime of a GPT can far outweigh the design and installation costs.

3.4.3 Maintenance

Regular maintenance is essential to ensure the performance of GPTs. Normally cleanouts are required around once every 3 months, however each trap should be monitored during the first few years of operation to determine the required cleanout frequency.

Poorly maintained GPTs can:

- Fail to trap pollutants.
- Release contaminants by leaching from the collected pollutants.
- Reduce the capacity of the drainage system and potentially lead to upstream flooding.
- Lead to unpleasant odours and reduced visual amenity.

The nature of maintenance activities depends to a large extent on the type of trap installed; this should be considered during the design stage. GPT suppliers are able to provide information on maintenance methods.

3.4.4 Further Information

Information on modelling GPTs in MUSIC is included in the “Stormwater Quality Modelling Guide”.

There are several different manufacturers of GPTs in Australia and each of them can provide detailed information on their products. Manufacturers include Baramy, CDS (Eimco Water Technologies), Ecosol, Nettech, Rocla, and others.

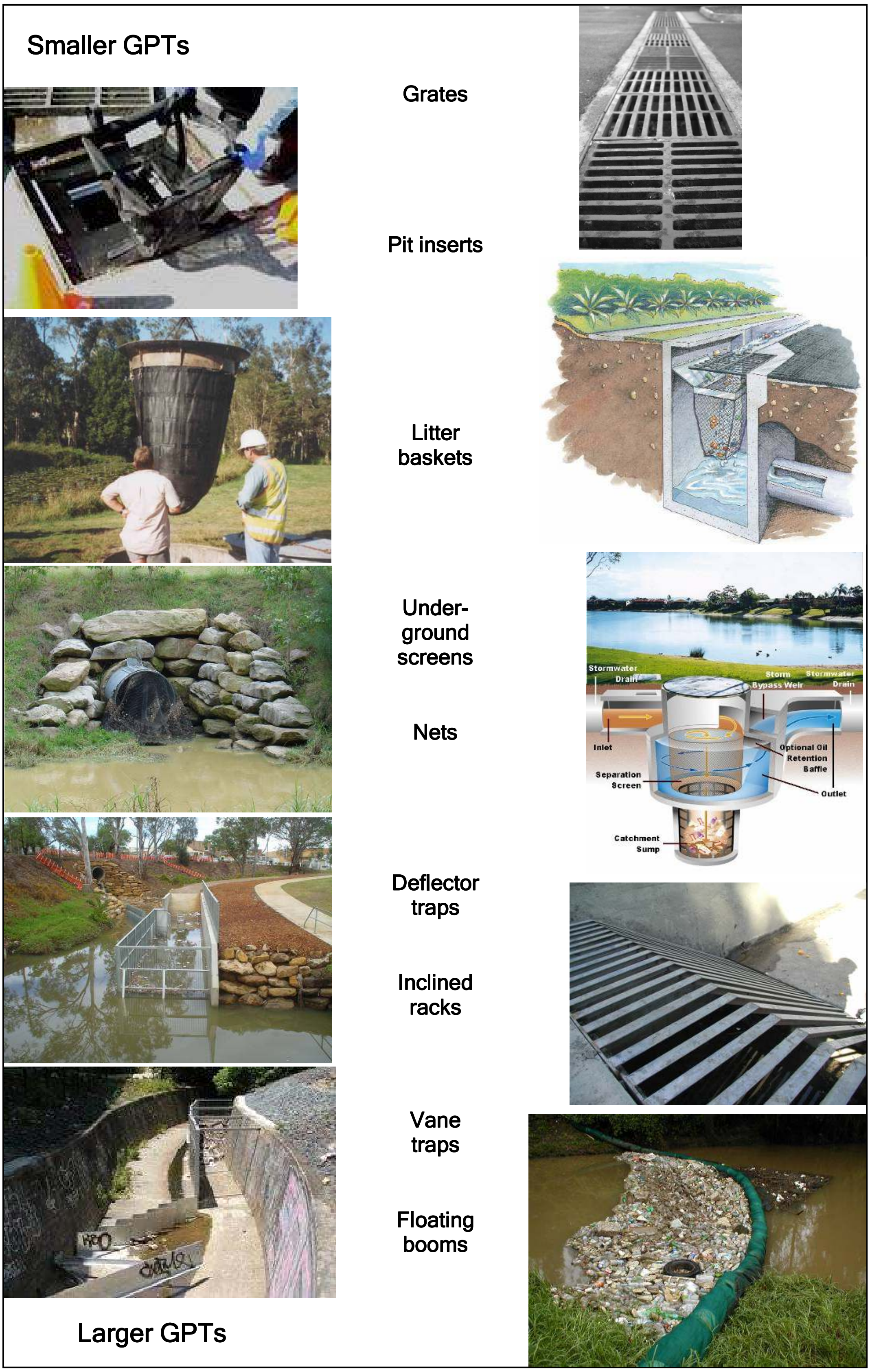


Figure 21: Typical range of gross pollutant traps

3.5 Stormwater Infiltration Systems

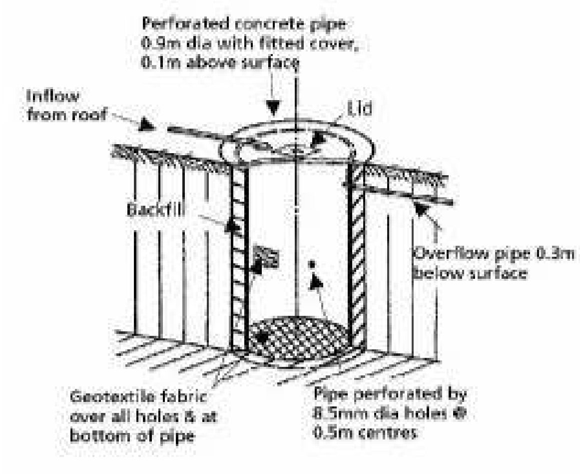
Stormwater infiltration systems are typically the last element in a treatment train, capturing stormwater and encouraging it to percolate through to surrounding soils and underlying groundwater. By detaining stormwater, infiltration systems reduce runoff peak flows and volumes, and hence help manage downstream flooding, and improve groundwater recharge. Infiltration systems provide the following functions:

- Aquifer recharge
- Minimising pollution conveyance to downstream water systems and receiving waterways
- Reduced post-development flows in regular rainfall events

Although infiltration systems minimise the pollution conveyed to downstream environments, an infiltration system will provide minimal water quality treatment. Generally pre-treatment for sediment, litter and debris is required to prevent clogging of the infiltration basin. Further pre treatment may be required if the infiltrate is being released to an aquifer or a ground water supply which will be reused to meet residential or irrigation water demands, or where the groundwater requires a certain water quality.

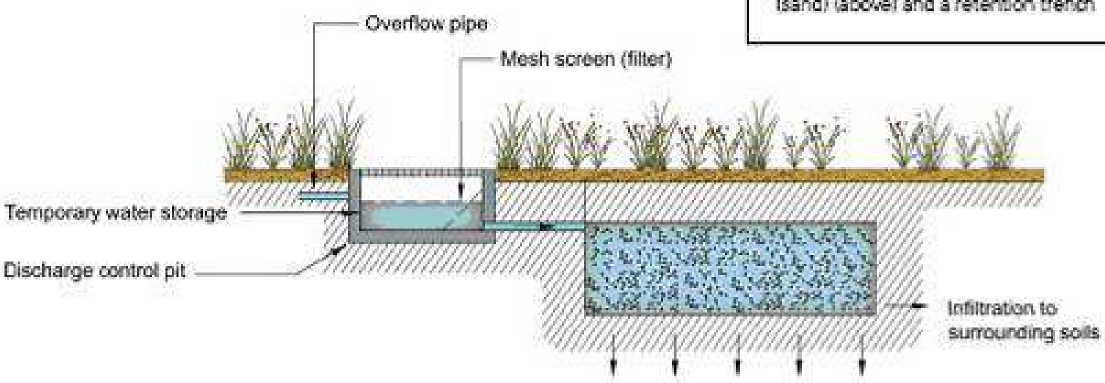
Infiltration systems typically consist of two sections; a detention volume and an infiltration area. The detention volume is designed to retain a certain volume of runoff, which when exceeded overflows to the downstream drainage system and receiving waterways. The interface between the captured runoff and the in-situ soils is defined as the infiltration area.

Infiltration systems commonly used in residential developments include leaky wells, retention trenches, infiltration “soak aways”, infiltration basins, infiltration cells and seepage pipes. Examples of a retention trench, infiltration basin (sand) and a leaky well are given in Figure 22.



Leaky well infiltration system (ARQ, 2006)

Built examples of an infiltration basin (sand) (above) and a retention trench



Infiltration "soak away" trench (Healthy Waterways, 2006)

Figure 22: Schematics and built examples of infiltration systems

3.5.1 Location

Infiltration is suitable where:

- Soil permeability is relatively high
- Groundwater is sufficiently deep
- Bedrock is sufficiently deep

It can be implemented at any scale, from individual lots to large subcatchments. Sediment contained in runoff can clog an infiltration system, reducing its hydraulic effectiveness. Hence, infiltration systems must be design to pre-treat stormwater with the potential to contain sediment, as well as litter and debris.

Infiltration systems can be incorporated as a component of other stormwater treatment measures. For example, a bioretention system can be constructed without an underdrainage system, and treated stormwater can discharge directly into the surrounding soil.

3.5.2 Design Considerations

The most important design consideration for an infiltration system is the site's geology, soils and groundwater. Soils need to have sufficient permeability to allow water to infiltrate without causing problems downstream. Unsuitable soils for infiltration systems include:

- Wind blown or loose sands
- Calcareous soils that collapse when in direct contact with retained runoff
- Soils with a hydraulic conductivity less than 0.36mm/hr
- Soils with a high salinity potential
- Sodic soils
- Reactive soils

Permeability testing and a soil assessment should be conducted where an infiltration system is proposed.

In-situ soil also needs to be able to convey infiltrated water to a groundwater system. Shallow soil cover over impervious bedrock (such as granite, shale and basalt) is unsuitable for infiltration. Only where rock is porous or fractured should infiltration systems be considered over shallow bedrock. A detailed engineering investigation should be conducted to verify rock will accept infiltrated runoff.

The base of an infiltration system should always be a minimum of 1m above the seasonal high water table. If shallow groundwater is likely, a site investigation should be conducted to assess the likelihood of mounding (the localise raining of the water table). Mounding can affect nearby structures similar to soil swelling.

Consideration should also be made of the environmental values of the underlying groundwater and any potential reuse options for the percolated runoff. An infiltration system provides minimal water treatment. Consequently, runoff should be treated to meet the water quality targets of the receiving water body and / or reuse application (e.g. irrigation, recreational).

3.5.3 Maintenance

It is suggested that the infiltration zone of an infiltration system be inspected every 1 – 6 months (depending on the size of the system), or after a major rainfall event. The inspections should consider:

- Surface ponding after rainfall events. Surface ponding is an indicator of clogging within the system. Clogging is alleviated by tilling the infiltration surface.
- Scouring and/or sediment accumulation in the inlet pipes, which should be removed at the time of inspection.

Clogging within the infiltration system and scouring / sediment accumulation in the inlet pipe will reflect poor pre-treatment of runoff. Properly maintained pre-treatment devises will reduce the frequency of inspections and the maintenance requirements for infiltration systems.

3.5.4 Further Information

For more detailed information on infiltration refer to the *Water Sensitive Urban Design Technical Design Guidelines for Southeast Queensland* (Moreton Bay Waterways and Catchments Partnership, 2006), available online at http://www.healthywaterways.org/wsud_technical_design_guidelines.html.

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