ZAM-WSUD Handbook

Zero Additional Maintenance Water Sensitive Urban Design
without ongoing maintenance requirements for asset owners

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The Zero Additional Maintenance Water Sensitive Urban Design (ZAM-WSUD) project is a collaboration between Manningham Council, Melbourne Water, the Cooperative Research Centre for Water Sensitive Cities and Monash Water for Liveability Centre. The project is supported by the City of Glen Eira.

The project was initiated by Manningham Council and has received funding support through the Melbourne Water Living Rivers Program. The project also received a financial contribution from the Co-operative Research Centre for Water Sensitive Cities.

Laboratory testing was conducted at the Monash Water for Liveability Centre.

Construction works to date, have been completed by Versini Constructions, Roadside Services and Solutions, VCrete Contractors and EnvirEng Civil.

Riversafe was initiated by Manningham Council and received funding support through the Melbourne Metropolitan Waste and Resource Recovery Group. Industry partner was Ecosol.

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www.clearwater.asn.au/resource-library/publications-and-reports/zero-additional-maintenance-water-sensitive-urban-design-zam-wsud-handbook.php

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1.1. What is ZAM-WSUD?

Water Sensitive Urban Design (WSUD) systems are local modifications to urban streetscapes that are designed to remove nutrients from stormwater and reduce peak flow volumes in waterways.

Conventionally designed WSUD installations require regular maintenance to allow these systems to continue to function effectively. Asset owners are now identifying that the ongoing maintenance requirements of these systems can be high relative to water cycle benefits. As a large number of WSUD installations are typically needed across waterway catchments in order achieve measurable improvements for receiving waterways, overall maintenance costs can be significant.

Zero Additional Maintenance Water Sensitive Urban Design (ZAM-WSUD) systems are WSUD systems designed to ensure that maintenance implications for asset owners are negligible. The design objective for a ZAM-WSUD installation is that the overall maintenance requirements at the installation location should not be increased by the inclusion of water quality improvement assets in the streetscape.

1.2. Why is ZAM-WSUD important?

ZAM-WSUD offers a cost effective way to transition to a water sensitive city, providing a broad range of water cycle benefits to communities, including improved waterway health, coastal nitrogen reduction, urban summer cooling, flood risk reduction and groundwater recharge. Consequently there is significant long-term value for asset owners and communities in developing and implementing Water Sensitive Urban Design systems with zero or very low maintenance implications for asset owners.

This handbook provides examples of urban street scale ZAM-WSUD installations and provides tools to assist designers and with future installations, based on installations constructed by Manningham Council as part of the ZAM-WSUD trial project.

Importantly, the ZAM-WSUD design philosophy can also be extended more broadly to a wider range of stormwater management systems. As a design objective, *zero additional maintenance* best ensures that new WSUD assets have minimal maintenance and ongoing cost implications for asset owners.

ZAM-WSUD systems to date have been constructed at the urban street scale, but may also be practical for medium and larger scale stormwater treatment systems.

Setting *zero additional maintenance* as a design objective for any stormwater quality improvement system, encourages innovation and improves the overall financial viability of a transition towards a water sensitive city.

ZAM-WSUD systems are WSUD systems designed to ensure that maintenance implications for asset owners are negligible

1.3. ZAM-WSUD initiatives

The ZAM-WSUD research project investigated typical maintenance requirements for street scale water sensitive urban design systems and developed alternative design solutions that remove ongoing maintenance requirements for asset owners.

These include:

- Grassed biofiltration,
- Vegetated *zero additional maintenance* biofilters,
- Tree based systems, and
- Automated gross pollutant collection.

New initiatives developed and implemented in the ZAM-WSUD trials were:

- Sediment grooves,
- Litter guard inlets, and
- ‘Clog resistant’ filter media profile.

ZAM-WSUD designs were originally developed for the retrofit of typical suburban residential streetscapes and car parks, but are also suitable for new urban developments, commercial sites and industrial areas.

Also, ZAM-WSUD principles can be used to develop *zero additional maintenance* designs for semi-rural and rural areas where roads are typically not bounded by formal concrete kerb edging.

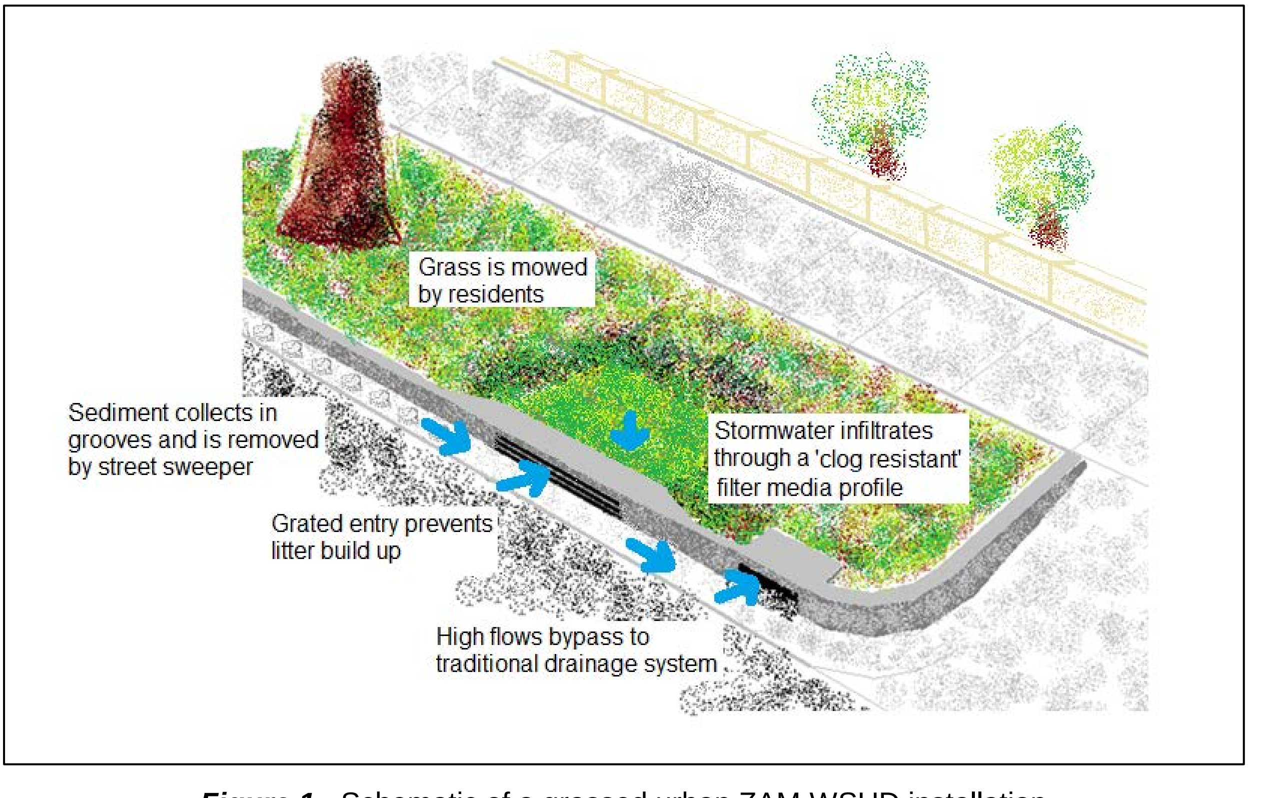

Figure 1 - Schematic of a grassed urban ZAM-WSUD installation

1.4. Grassed biofiltration

The ZAM-WSUD research project identified that grassed biofilter systems could meet the *zero additional maintenance* objective when installed in a typical suburban nature strip. Normal grass mowing arrangements (by residents, Council or others) provides regular removal of vegetation growth, effectively removing nutrients from the biofiltration system and ensuring that it can continue to effectively treat stormwater in the long term.

Research trials undertaken previously at Monash University (Payne et Alia, 2014) identified that Soft Leaf Buffalo grasses (*Palmetto* and *Sapphire cultivars*) effectively remove nitrogen and phosphorous from stormwater passing through a sand filtration system.

Field trials of the *Palmetto SS100 cultivar* undertaken in Manningham between 2014 and 2016, identified some incompatibility between Buffalo species and biofilter sands, particularly during establishment, for "full sun" sites with dry soils. Comparative grass field trails (2016) indicated that Kenda Kikuyu and Empire Zoysia have improved initial survival characteristics in sandy soils compared to soft leafed buffalo cultivars.

Nara Native Zoysia	Soft Leaf Buffalo Palmetto	Kenda Kikuyu	Empire Zoysia	Soft Leaf Buffalo Sapphire

Figure 2 - Grass condition at four months after planting at site with very high pedestrian traffic

ZAM-WSUD alternative grass species laboratory trials (Fowdar, 2017) confirmed that a range of grass species are very effective at removing nitrogen and phosphorous from stormwater. The trials demonstrated that at maturity (after one year) biofitration systems planted with sterile male Kikuyu (Kenda and Village Green), Couch (Santa Ana), Zoysia species (Empire and Nara Native) and Soft Leaf Buffalo (Palmetto and Sapphire), can all achieve well above 'best practice' removal of nitrogen (45%) and phosphorous (45%)[1]. Trials demonstrated total nitrogen removal rates at maturity above 70% for all species - under both wet and dry conditions.

Many grass species are very effective at removing nitrogen and phosphorous from stormwater

[1] 'Best practice' as per Stormwater Victoria, 1999, Urban Stormwater Best Practice Environmental Management Guidelines.

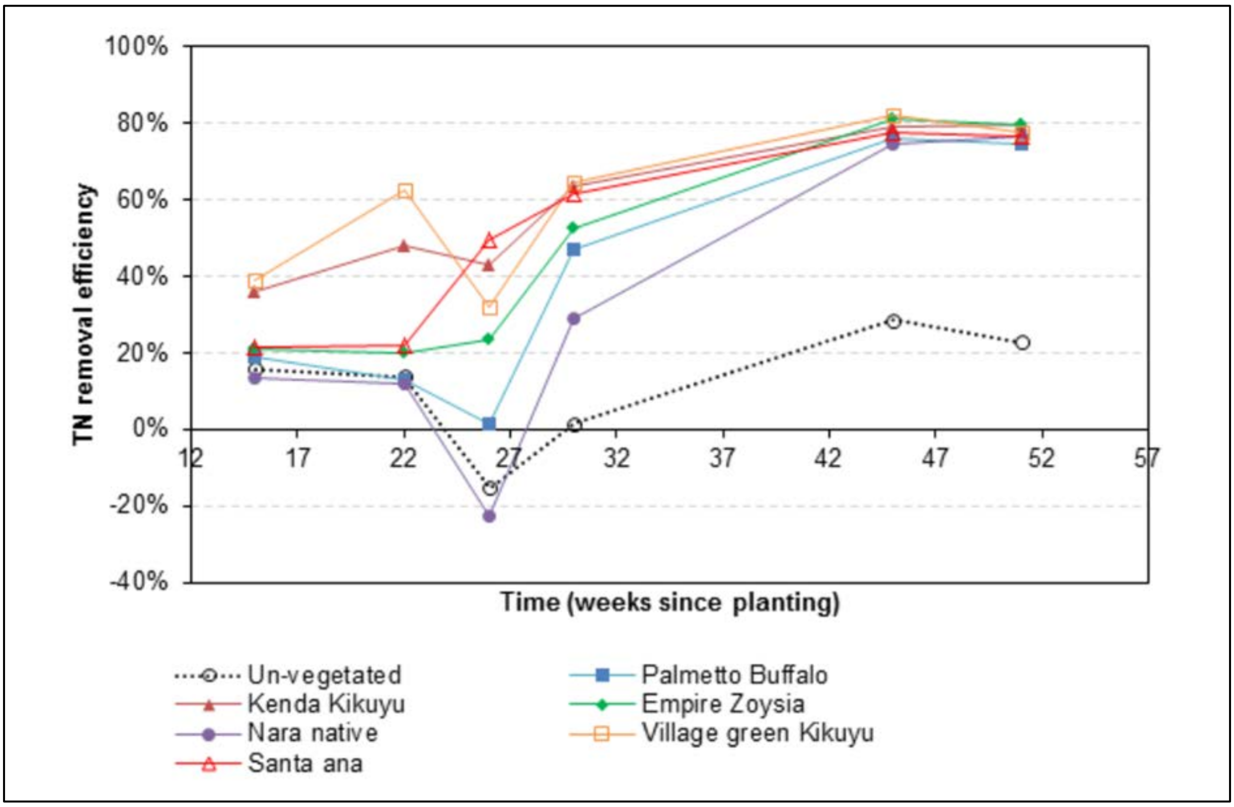

Figure 3 - Total Nitrogen removal results under wet (30 & 45 weeks) and dry (26 & 52 weeks) conditions in grassed ZAM-WSUD biofilter laboratory trials. (Fowdar, 2017)

Field testing of established ZAM-WSUD installations (Al-Ameri et alia, 2018) confirmed that in-field ZAM-WSUD installations achieve best practice[1] removal for nitrogen, phosphorous, Total Suspended Solids (TSS), copper and zinc from stormwater.

Observations to date have identified that for south eastern Australian climates, sterile male Kikuyu species (Kenda and Village Green) are suitable for ZAM-WSUD installations in sunny locations (<20% shade). Zoysia species may be more suitable for low to medium pedestrian traffic sites with part shade (20-40%).

1.5. Vegetated Zero Additional Maintenance Biofilters

Vegetated WSUD systems can also be designed based on a *zero additional maintenance* objective.

For areas where feature landscaping is existing or proposed for aesthetic reasons, a vegetated ZAM-WSUD system can be installed with similar maintenance requirements to a typical landscaped area, so that the design criteria of *zero additional maintenance* is still achieved. Occasional ZAM-WSUD weed removal and vegetation trimming will be required, but this is not expected to be more than for other feature landscaping areas.

Inclusion of the surface ‘protection layer’ of 20/30 course sand has been shown to significantly reduce weed growth in vegetated ZAM-WSUD systems installed to date. The selection of plant species with low foliage growth rates will also minimise trimming requirements.

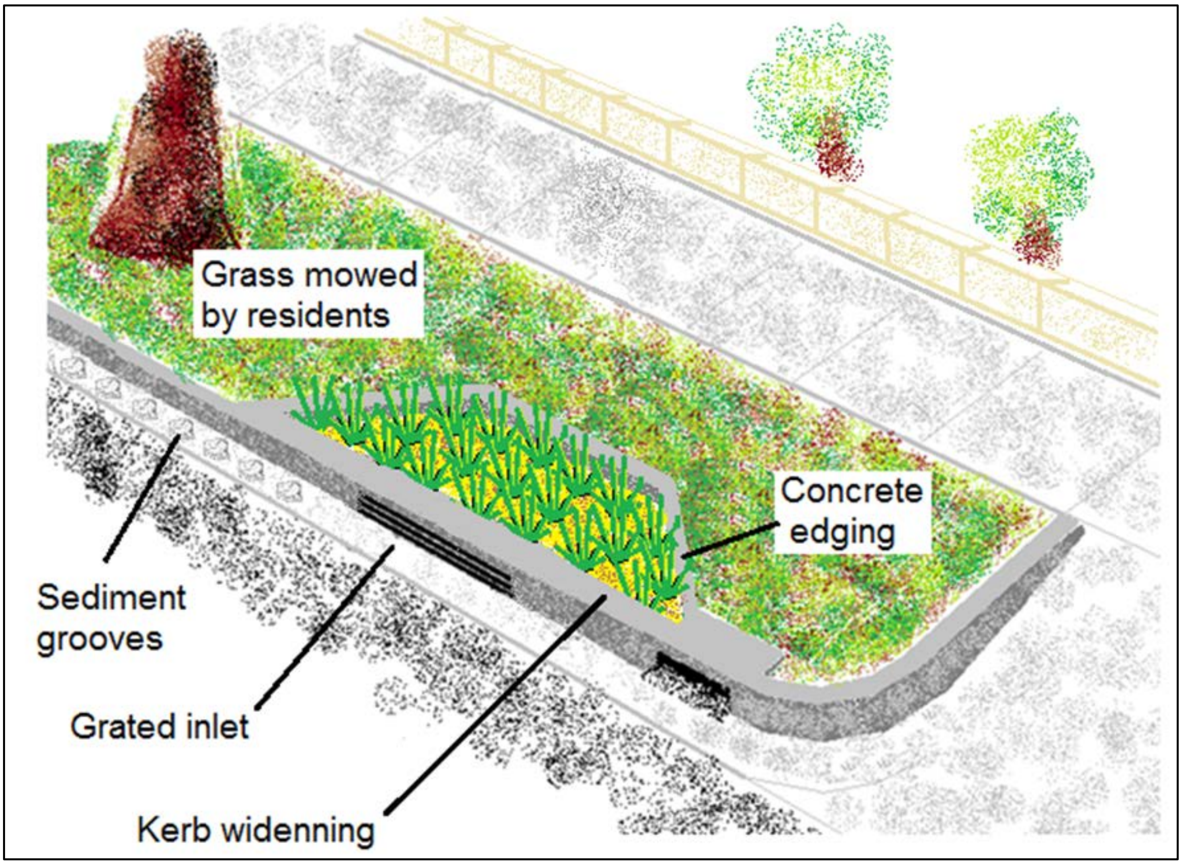

Figure 4 - Sketch of an urban streetscape vegetated ZAM-WSUD installation

To ensure that vegetated ZAM-WSUD systems are effective at removing nitrogen, it is recommended that at least 50% of selected plants be effective at nitrogen removal.

Suitable species for nitrogen reduction are recommended in Ad*option Guidelines for Stormwater Biofiltration Systems – Summary Report* (Payne et alia, 2015). Species from this list that are more suitable for general vegetated ZAM-WSUD installations are: Goodenia ovata, Juncus flavidus, Baumea rubiginosa and Ficinia nodosa. The remainder of plants can be selected to suit aesthetic considerations, but species that fix nitrogen should be avoided (such as legumes and actinorhizal plants).

1.6. Tree based WSUD systems

The capacity of trees to absorb water is now understood to be well beyond infiltration and evapotranspiration rates combined, and is perhaps best understood in terms of the potential for tree roots to act as 'micro pipes' allowing relatively rapid hydraulic redistribution of water across the entire tree root zone, (Johnson, T, 2017, personal comment).

Studies of northern hemisphere vegetation (Lambers et al. 1998, based on Milburn, 1979 and Zimmerman and Milburn, 1982) have confirmed relatively high water velocities though tree roots (0.1 to 12.1mm per second).

Similar data may not yet be available for Australian vegetation types, but Australian tree species such as

Eucalypts and Melaleucas are well recognised as having a very high water uptake capacity.

Eucalyptus camaldulensis, E. tereticornis and E. brassiana are now being extensively planted in Bangladesh to lower groundwater tables, providing flood protection by increasing the capacity for soils to store water during high rainfall events.

As such, tree based WSUD systems offer increased total water cycle benefits by increasing infiltration rates. *TreeNet* inlets systems, developed in South Australia through treenet.org, offer a low cost, *zero additional maintenance* WSUD system suitable for urban streetscapes.

These systems provide multiple water cycle benefits, including nutrient capture, flood volume reduction, groundwater recharge and street tree drought resilience.

The capacity of trees to absorb water is now understood to be well beyond infiltration and evapotranspiration rates combined.

Inlets include features that minimise maintenance requirements such as:

- A local depression that creates a vortex, diverting solid materials away from the inlet.
- Raised inlet invert to prevent gravel entry.
- Automated cleaning of inlet and depression by existing street sweeper operations.
- Bio-composting of captured organic materials by soil biota.

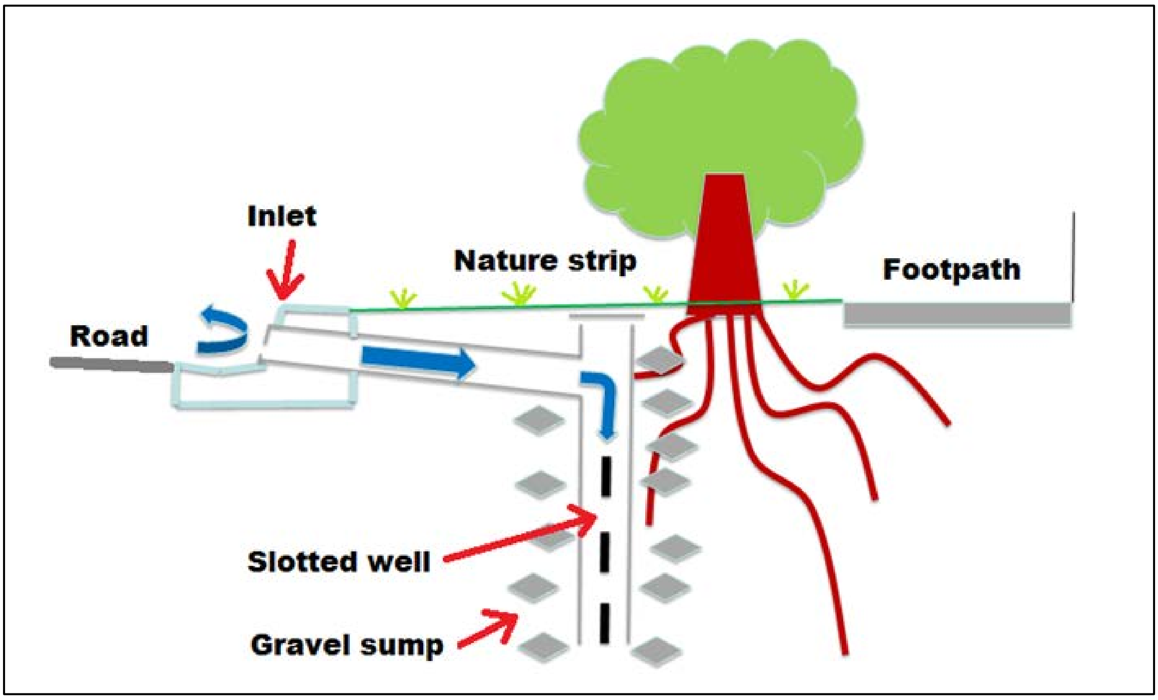

Figure 5 - Cross section of a *TreeNet* inlet system

1.7. Gross pollutant capture

The potential for a **Zero Additional Maintenance Gross Pollutant Trap** (ZAM-GPT) was identified and investigated during a three year research project. The project developed *Riversafe*, a combined street litter bin and gross pollutant trap, suitable for automated collection by a standard domestic garbage truck.

The design achieves the *zero additional maintenance* objective when installed in activity centres where litter bins are already situated, as gross pollutants are emptied at the same time as street litter bin emptying. *Riversafe* is now available through industry partners Ecosol.

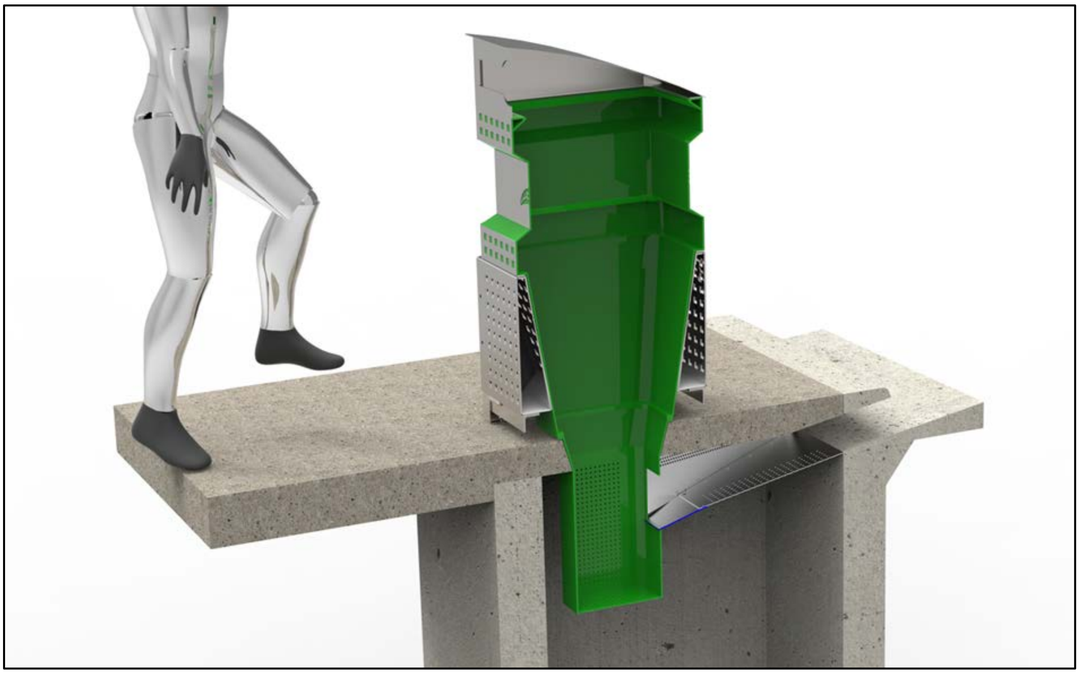

Figure 6 - *Riversafe* is a combined street litter bin and gross pollutant trap

Figure 7 - Automated emptying of *Riversafe*

1.8. Sediment grooves

Biofiltration systems are susceptible to filter media clogging if large amounts of fine sediment (typically silts) enter the biofiltration system and form a thin impervious surface layer that can prevent water entry to subsurface layers. Sediment capture and collection prior to a biofiltration system reduces sediment quantities entering a biofilter, reducing the risk of clogging and helping to ensure that systems can function effectively in the long term, without requiring sediment removal and/or filter media replacement.

Figure 8 - Deposition in a sediment groove prototype and constructed sediment grooves

ZAM-WSUD sediment grooves were designed to capture sediment and to allow collected sediment to be effectively removed by street sweepers during routine street-sweeping, (typically every 5 to 6 weeks). Field testing (with a MacDonald Johnston VT605 Sweeper) confirmed that 1V:4H side and rear gradients were optimal to allow sediment grooves to be effectively cleaned out. Bed width was selected as 50mm to ensure adequate collection capacity and to moderate risks to pedestrians and cyclists.

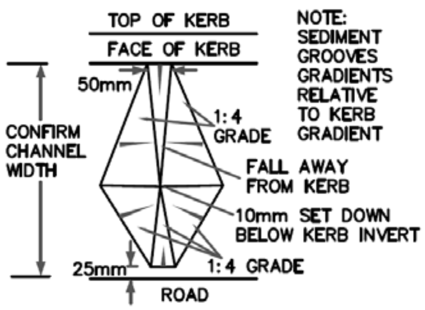

Figure 9 - Field trials to design sediment grooves and the modified sediment groove design

Sediment groove bed gradient was originally designed as flat and level with the kerb invert, to prevent water ponding. Field trials (Al-Ameri et alia, 2018) identified that *flat bed* grooves are only partly effective at removing total suspended solids (around 10% reduction). Field observations have confirmed that suspended solids capture effectiveness is increased if sediment grove geometry includes a small setdown from kerb invert level that allows a small amount of water to pond at the base of the groove.

1.9. Grated Inlets

Communities expect that urban streetscapes are neat, tidy and free from visual litter. Conventional biofiltration systems accumulate litter as design directs litter carried by stormwater into the filtration area. To meet community expectations regular inspection and litter removal are required as visual litter remaining in these systems, even for a short period of time, can trigger community complaints. To address this issue and achieve the *zero additional maintenance* objective, ZAM-WSUD systems include litter guards, preventing larger litter from entering the bio-treatment area.

Design and prototyping identified that horizontal square bars with 18mm to 20mm gaps are effective at preventing litter entry without inlet clogging issues. Inlet grates were designed so that the inlet grill is flush with the existing kerb so that the inlet face can be effectively cleaned by street sweepers as part of normal street sweeping. Due to the potential for abrasive damage from stainless steel street sweeper brushes, 304 stainless steel has been identified as the preferred construction material for grates. Barrier kerb inlets are now commercially available in 304 stainless steel, but more complex grates, such as for rollover kerbs, are available in hot dip galvanised steel.

Communities expect that urban streetscapes are neat, tidy and free from visual litter.

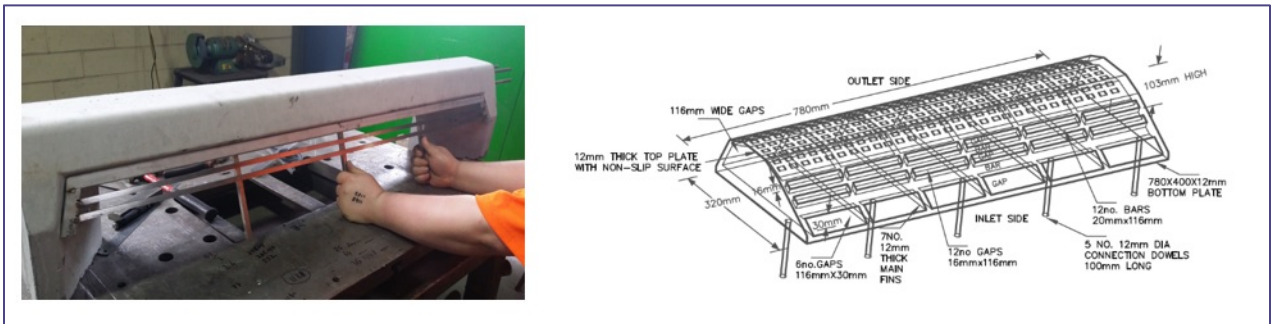

Figure 10 – 304SS grated inlet for barrier kerb, and hot dip galvanised inlet for rollover kerb

In-field trials have confirmed that horizontal bar ZAM-WSUD inlets are effective and do not clog. Some small sized litter and organic matter (e.g. leaves) may still pass through inlet grates. For grassed ZAM-WSUD systems this material will be collected during grass mowing.

TreeNet inlets have similar inlet features, including a horizontal inlet and stainless steel construction. As gross pollutants bypass ZAM-WSUD inlets, it may be appropriate to consider other methods of gross pollutant collection within the catchment, particularly for any 'litter hotspots' locations.

Figure 11 - *TreeNet* inlet system

1.10. Clog resistant filter media profile

Biofilter media clogging has been a problem for some WSUD installations where high sediment loads occur before vegetation is well established. Filter media clogging is caused by the formation of a thin impervious layer of sediment at the top of the FAWB specification filter media sand.

A preliminary literature review by Monash University researchers, indicated the potential to reduce the incidence of surface layer clogging by the inclusion of an additional coarse sand surface layer capable of "absorbing" silt within void spaces. Laboratory trials undertaken at Monash University as part of the ZAM-WSUD project (Hatt et alia, 2014) confirmed the suitability of this strategy and identified that transition layer 20/30 sand was also a suitable material for the protection layer.

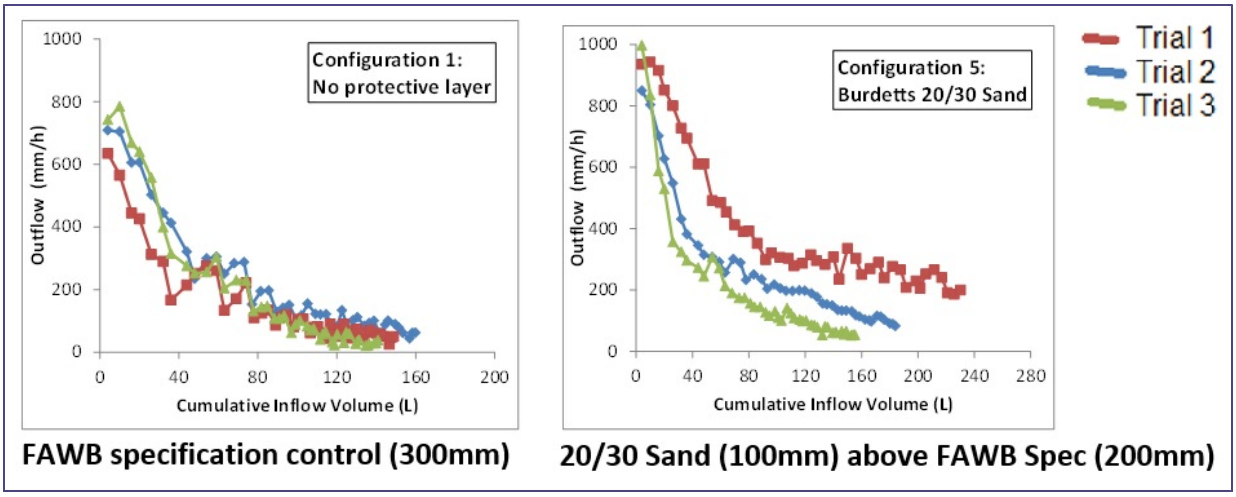

Figure 12 - Improved filter media clog resistance with the with the inclusion of a coarse 20/30 sand protective layer during intensive application of 18 months of stormwater nutrients applied over 15 days

For ZAM-WSUD installations, the inclusion of a protective layer is expected to provide significant long term resilience against clogging as in-field clog resistance is also enhanced by additional wetting and drying cycles, plant root growth and soil biota growth that all increase soil porosity. Suitable sands for the protection layer have a high percentage of particles between 0.5mm and 2mm in diameter, and very little fines (<3% total for fine sand, very fine sand, silt and clays).

Typical protection layer particle size distribution (20/30 sand)

Sediment	Particle Size (mm)	Percentage (%)
Fine Gravel	2.0	2
Very Course Sand	1.0	13
Coarse Sand	0.5	61
Medium Sand	0.25	21
Fine Sand	0.15	1
Very Fine Sand	0.05	2
Silt and Clay	<0.05	Trace
Hydraulic Conductivity Drainage (mm/hr)	1316	
Texture	Off white sand	

2. Practical ZAM-WSUD examples

2.1. Grassed

Grassed ZAM-WSUD installations were retrofitted into existing streetscapes at six sites across Manningham in 2016 and 2017.

Figure 13 - **ZAM-WSUD Prototype** - Manningham Council Depot, Blackburn Road, Doncaster East

Figure 14 - **Single barrier kerb installation** - Park Avenue, Doncaster

Figure 15 - **Single barrier kerb installation** - Hummel Way, Doncaster

Figure 16 - **Single barrier kerb installation -** Edwin Street, Templestowe

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Figure 17 - **Roll over kerb installations** - Sanctuary Place, Templestowe

Figure 18 - **Barrier kerb installations** - Ruffey Lake Car Park, Victoria Street, Doncaster

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2.2. Tree Based

TreeNet inlets installed on nature strips reduce pollutant loads entering waterways and also provide a range of other water cycle benefits including flood protection, groundwater recharge and street tree drought resilience.

***Figure 19 - Treenet* inlet** - Chadsworth Quadrant, Lower Templestowe

Figure 20 - TreeNet inlet - retrofit prior to backfilling, Hodgson Street, Lower Templestowe

Figure 21 - TreeNet inlet - Jeffrey Street, Lower Templestowe

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2.3. Vegetated

Vegetated ZAM-WSUD installations have been installed at a number of sites in Manningham to provide both feature landscaping and water cycle improvement.

***Figure 22 -* Vegetated ZAM-WSUD installation** - Mullum Mullum Reserve, Donvale

***Figure 23 -* Existing rain-garden inlet retrofit** - Worrell Street, Nunawading

***Figure 24 -* Vegetated ZAM-WSUD installation** - Highview Drive, Doncaster

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2.4. Gross pollutant capture

Trial *Riversafe* combined street litter bins and gross pollutant traps, have been installed at six locations across Manningham targeting 'litter hotspot' areas.

***Figure 25 - Riversafe* Installation** – Hopetoun Road, Park Orchards

Figure 26 - *Automated emptying of a* Riversafe *bin* ***- Templestowe Village, Templestowe***

***Figure 27 - Riversafe* Installation** – JJ Tully Drive, Doncaster

Figure 28 - Riversafe – Blackburn Road, Doncaster East

3. Site Selection

The following factors need to be considered when assessing the suitability of a proposed site for a ZAM-WSUD system.

3.1. Strategic Planning

A combination of ZAM-WSUD biofiltration systems and gross pollutant controls such as ZAM-GPTs can provide a complete, stand-alone water sensitive catchment solution. Strategic coordination of installations is recommended to determine whether local ZAM-WSUD or larger end-of-line treatment systems are most appropriated for a particular catchment or sub-catchment.

3.2. Catchment area and size

Street scale ZAM-WSUD biofiltration systems are best located just upstream of a stormwater pit to allow stormwater from the largest catchment area to be captured and treated.

The recommended treatment area for conventional WSUD systems is 1-2% of the impervious catchment area to provide effective treatment and resistance to clogging. ZAM-WSUD biofiltration systems are able function effectively with larger catchment areas as they include sediment pre-capture and a clog resistant filter media profile. Grassed ZAM-WSUD installations with treatment areas around $2m^2$ are operating effectively with impervious catchment areas up to $400m^2$.

Tree based WSUD systems such as TreeNet inlets are typically installed with smaller impervious catchment areas, typically up to $100m^2$. For residential areas, TreeNet installations are often installed adjacent to street trees on each nature strip, to maximise the full range of water cycle benefits.

3.3. Suitable road gradients

Grassed ZAM-WSUD systems are operating successfully on roads with longitudinal gradients up to 1V:10H, but grades flatter than 1V:15H are preferable as there may be some filer media movement during the grass establishment phase for sites with gradients exceeding 1V:15H. Additional velocity control measures behind the inlet grate, such as rocks embedded in the apron, can reduce velocities and prevent scouring.

3.4. Underground services

Conflicts with existing underground services can make grassed or vegetated biofilter retrofit installations impractical and/or very costly. As road reserves typically contain many underground services, it essential to obtain underground services information when assessing the suitability of a potential ZAM-WSUD site. ZAM-WSUD biofilter systems require a connection to the piped drainage network, so are most cost effective when constructed in close proximity to an existing drainage pit.

As *TreeNet* inlets have a very small footprint below 300mm depth, these systems can easily be constructed using non-destructive excavation equipment, so can be installed successfully in most nature strips - even with multiple underground services.

3.5. Street Trees

WSUD systems have typically been constructed well away from trees to minimise the potential for tree root entry into ag drains. More recent thinking suggests that tree roots can potentially enhance the infiltration functionality of WSUD systems. ZAM-WSUD systems to date have been constructed outside of tree canopies to minimise construction phase root damage and to best ensure grass and/or vegetation survival.

TreeNet inlet systems are best installed on the upstream (high) side of street trees and as close to the trunk as practical without significantly impacting on structural roots. For new trees, sumps can be installed around 1.5m from the trunk. For larger trees sumps often need to be constructed close to the canopy drip line due to practicalities of operating excavation equipment under the canopy.

3.6. Vehicle compaction

Biofilter installations should be avoided in locations where vehicles are parked on the nature strip. This compacts the filter media reducing hydraulic conductivity and increasing the susceptibility to clogging. Subtle physical barriers, such as strategically positioned street signs, can help to protect ZAM-WSUD assets from vehicle compaction.

3.7. Nature strip width and crossfall

Grassed ZAM-WSUD systems generally require 2m or wider nature strips. Footpath level must not be significantly elevated above the level of the top of kerb. The allowable height difference is around 10cm, but wider nature strips provide more flexibility.

These requirements ensure that batter slopes are no steeper than 1V:5H, allowing mow-ability and ease of pedestrian use. Vegetated systems that include a rear retaining sleeper can be constructed on narrower nature strips.

3.8. Resident/community acceptance of ZAM-WSUD assets

Gaining local community acceptance of ZAM-WSUD assets is essential to any successful installation.

This is particularly important for installations outside residential properties where residents will be responsible for mowing the grass. For these installations it is recommended that resident consultation be part of the site selection process. In some situations it may be possible to offer residents a choice of installation type.

An asset which has received acceptance from residents prior to construction will have a far better long term prospects than an asset that has been installed without appropriate consultation or acceptance.

In some situations it may be possible to offer residents a choice of installation type.

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4. Detailed Design

A range of factors need to be considered when designing a ZAM-WSUD biofilter system.

4.1. Saturated zone

The saturated zone holds water and is very important for ensuring that ZAM-WSUD systems are resilient during extended dry periods. ZAM-WSUD systems need to be specifically designed and constructed to ensure that a submerged zone is created. An impermeable geomembrane is typically used to seal the bottom of a ZAM-WSUD system. However, where soils are impermeable clays, a geomembrane may not be required. The slotted ag pipe within the no fines crushed rock drainage layer also needs to be connected to a drainage pit using an unslotted pipe outlet riser in a *raised elbow* configuration, so that water is trapped in the base of system.

The outlet riser should be installed so that the saturated water level is set just below the level of the FAWB specification filter media to maintain aerobic conditions within the filter media.

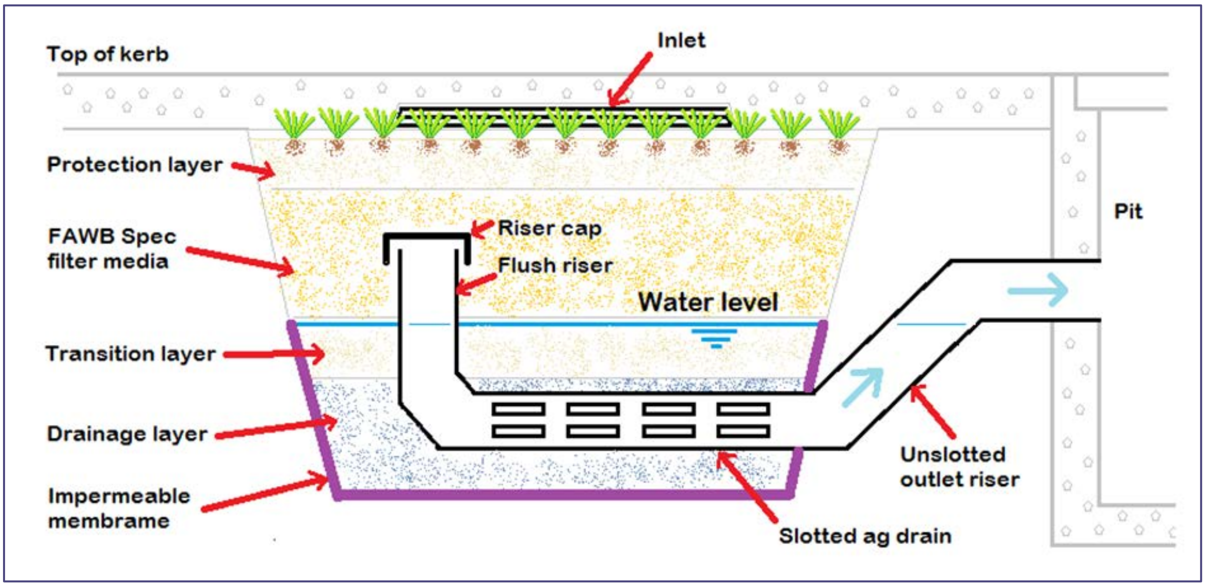

Figure 29 - Saturated zone created using an impermeable membrane and an unslotted outer riser

4.2. Trip hazards

ZAM-WSUD biofilter systems require a local lowering of nature strip levels to allow stormwater to flow over the biofilter surface. This set down can create additional trip hazards, so installations will not be appropriate for all sites, particularly where there are high traffic volumes moving at speed directly adjacent to the kerb. Design elements that minimise trip hazard potential include:

- Utilising a double lintel (back to back) to provide a 400mm wide step to assist persons exiting vehicles, and providing a strong visual differentiation compared to adjacent kerbing,
- Limiting step down height from the top of kerb to the ZAM-WSUD bed to approx. 200mm,

- Selecting sites in proximity to street lighting and/or using luminescent concrete,
- Allowing for a 300mm wide strip adjacent to footpaths with a cross fall not exceeding 1V:10H.

4.3. Number of sediment grooves

Sediment grooves that allow some ponding can reduce sediment and suspended solid loads entering ZAM-WSUD systems extending asset life expectancy. Installations to date have been installed with up to 12 no. sediment grooves for impervious catchment areas greater than 150m².

4.4. Vandalism protection and structural integrity

Streetscape installations need to be robust such that they are not susceptible to physical damage or vandalism. During trials inlet grates included “legs” that were cast into concrete so that the grates could not be removed.

Base concrete thickening to 150mm minimum, and steel bar reinforcement above inlets are recommended to prevent structural cracking.

Excessive cyclic localised saturation and drying of road subgrade and subbase materials can accelerate structural deterioration and/or subsidence of base materials. Including an impermeable geomembrane layer between the filter media and the road subgrade and subbase materials will limit localised water inflow to subgrade materials and prevent any associated accelerated road pavement degradation.

4.5. Concrete Apron

A concrete apron at the back of kerbing improves mow-ability by allowing grass to be mowed with a standard lawn mower without needing specialised edge trimming equipment such as a brush cutter.

***Figure 30* - Concrete apron retrofit** - Edwin Street, Templestowe

***Figure 31* - Concrete apron** – Park Avenue, Donvale

5. Construction

ZAM-WSUD assets must be constructed in accordance with general civil construction industry best practice. Appropriate and adequate systems are needed for occupational health and safety, traffic management, pedestrian management, quality control, underground service identification, service authority engagement, works permits and environmental protection.

There are a number of specific construction requirements for ZAM-WSUD systems to ensure that installations are fit for purpose and can achieve the *zero additional maintenance* objective.

5.1. Validation of filter materials

For a WSUD system to function effectively, correct sand types must be used. Sand types for biofilters are now commercially available through major suppliers.

Visual inspections and the provision of receipts from suppliers may be adequate in many cases to confirm that the correct sand types have been used. If there is any concern about the suitability of materials being used, samples can be sent to a NATA approved geotechnical laboratory for hydraulic conductivity testing and particle size analysis to confirm whether the material used is suitable.

Collection of uncontaminated filter media samples at the time of construction is recommended so that if there are any later concerns about system performance, samples are available for testing.

Figure 32 - Filter media materials used for ZAM-WSUD biofilter installations

5.2. Preventing filter media contamination

Contamination of filter media sands with excessive construction dirt can cause short term clogging and failure of the filter media. An appropriate methodology needs to be developed by contractors to ensure that this does not occur.

Suitable protection measures during construction include placing and removing a sacrificial sand layer, placing a cover over the filter media, delaying sand placement until the completion of civil works and/or blocking the ZAM-WSUD inlet during construction.

5.3. Sediment groove construction

Sediment grooves constructed to date have been constructed by hand. The method used involved roughly constructing kerbing, rough hand trowel construction, mould pressing, slurry placement, mould pressing (again) and hand trowel finishing.

Concrete needs to be protected from vehicles for a number of days to minimise the risk of cracking.

***Figure 33* - Sediment groove installation** – Park Avenue, Doncaster

5.4. Establishment

It is essential that grass is kept moist:

- during transport,
- immediately after placement, and
- for the first six weeks at least after placement.

If grass dries out before it is well established, it may not fully recover. Appropriate arrangements need be made for regular watering at least every second day unless rainfall is regular. Mid-autumn planting is preferable to minimise watering requirements and maximise establishment time before the next summer.

Top dressing of turf assists with moisture retention. As there may be some subsidence and movement of top dressing sand during establishment, a site inspection is recommended around six weeks after planting. Placement of additional 20/30 sand may be needed.

Chemical weed spraying (such edge spraying) must not be carried out during the establishment phase and should be avoided in general.

Mid-autumn planting is preferable to minimise watering requirements and maximise establishment time.

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Grasses typically prefer a pH between 5.8 and 6.5. Leaching of calcium carbonate from concrete following placement can increase soil pH which can adversely affect grass/plant establishment and survival. Soils and filter media with a pH of around 6 are preferable to offset any increases in soil alkalinity. Soil pH test kits are generally available from garden suppliers.

Successful establishment of a grassed WSUD system requires grass to be kept moist for an extended period, especially for the first six weeks after planting. As a consequence ZAM-WSUD systems are best established in mid-autumn. Watering is typically needed every second day unless rainfall is regular. A depth of 10-15mm depth of 20/30 sand is recommended for this.

Amelioration of the sand layer directly below the turf with organic matter, fertiliser and trace elements during installation is recommended to assist with grass establishment.

6. ZAM-WSUD Trial Sites

The location of existing ZAM-WSUD and TreeNet installations within the Manningham municipality is shown on the figure below and in the subsequent table.

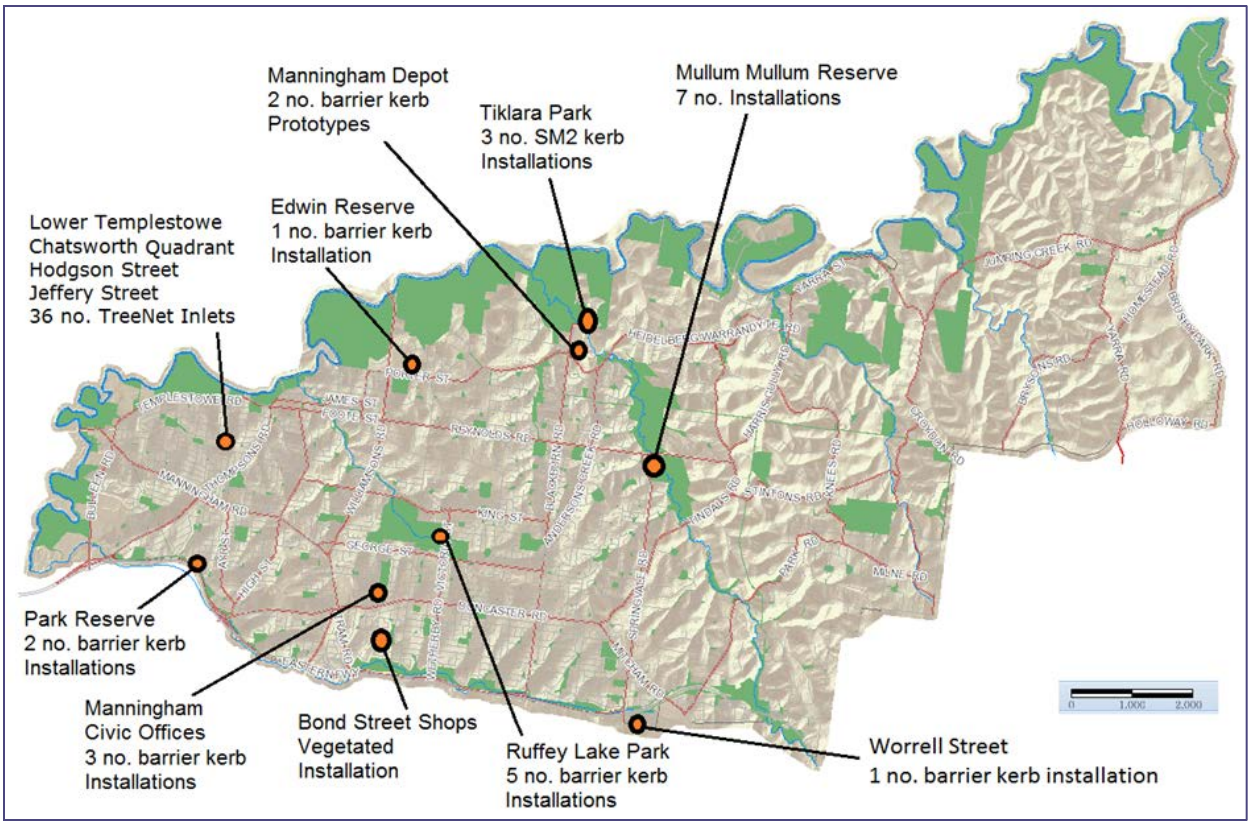

Figure 34 - ZAM-WSUD locations within Manningham

Site	Street Address	Suburb	Melways Ref
Manningham Depot	620-628 Blackburn Road (staff car park)	Doncaster East	34 D3
Tikilara Park	Sanctuary Place	Templestowe	34 E1
Manningham Civic Offices	Hummel Way	Doncaster	33 F12
Ruffey Lake Park	Victoria Street Car Park	Doncaster	33 J10
Park Reserve	Park Avenue	Doncaster	32 J12
Edwin Reserve	Edwin Road	Templestowe	33 G3
Bond Street Shops	Corner Bond Street and Highview Drive	Doncaster	47 F2
Mullum Mullum Reserve	Corner Reynolds and Springvale Roads	Donvale	34 H7
Worrell Street Shops	Worrell Street	Nunawading	48 G6

7. Construction Toolkit

Standard drawings and a technical specification (refer to attachments) have been developed to assist future ZAM-WSUD installations. Standards drawings have been developed for barrier, semi-mountable, rollover and mountable (M2) kerb types.

MCC Drawing No.	Vegetation	Kerb Type	Title	Refer to
S404	Grassed	Barrier (BK)	ZAM-WSUD Grassed – For Barrier Kerb	Attachment 1
S405	Grassed	Semi-mountable (SM)	ZAM-WSUD Grassed – For SM Kerb	Attachment 2
S406	Grassed	Rollover	ZAM-WSUD Grassed – For Roll Over Kerb	Attachment 3
S407	Grassed	Mountable (M2)	ZAM-WSUD Grassed – For Mountable (M2) Kerb	Attachment 4
S408	Vegetated	Barrier (BK)	ZAM-WSUD Vegetated – For Barrier Kerb	Attachment 5
Treenet	Tree	Barrier (BK)	TreeNet for Barrier Kerb	Attachment 6

The technical specification (Attachment 7) provides recommended details for the successful construction of ZAM-WSUD and TreeNet installations including materials and installation methodologies.

Standard drawings and technical specifications are designed to by accompanied by other supporting information including site specific plans, general civil technical specifications and contractor OH&S system requirements.

MANNINGHAM

8. References

1. Belinda Hatt, Veljko Prodanovic and Ana Deletic (2014) *Zero Additional Maintenance WSUD Systems: Clogging Potential of Alternative Filter Media Arrangements*. Monash University Water for Liveability Centre (Attachment 8)

2. Emily G. I. Payne, Tracey Pham, Perran L. M. Cook, Tim D. Fletcher, Belinda E. Hatt and Ana Deletic (2014) Biofilter design for effective nitrogen removal from stormwater – influence of plant species, inflow hydrology and use of a saturated zone. *Water Science and Technology* 69.6.

3. FAWB (2009) *Adoption Guidelines for Stormwater Biofiltration Systems*, Facility for Advancing Water Biofiltration, Monash University

4. Payne et alia (2015) *Adoption Guidelines for Stormwater Biofiltration Systems – Summary Report*, Cooperative Research Centre for Water Sensitive Cities

5. Fowdar et alia (2018) *The performance of turf grass species in ZAM-WSUD stormwater biofilters, Final report*, Manningham Council and Monash University (Attachment 9)

6. Al-Ameri, M. Deletic, A. Hatt, B, Brink, S. (2018) *Zero Additional Maintenance Water Sensitive Urban Design (ZAM-WSUD) Systems: Hydrologic and Pollutant Removal Performance at the Field Scale – Final Report,* Monash University and Manningham City Council

9. Attachments

1. Grassed ZAM-WSUD – For Barrier Kerb
2. Grassed ZAM-WSUD – For SM Kerb
3. Grassed ZAM-WSUD – For Roll Over Kerb
4. Grassed ZAM-WSUD – For Mountable (M2) Kerb
5. Vegetated ZAM-WSUD – For Barrier Kerb
6. TreeNet for Barrier Kerb
7. ZAM-WSUD Technical specification
8. Zero additional maintenance WSUD systems: clogging potential of alternative filter media arrangements.
9. The performance of turf grass species in ZAM-WSUD stormwater biofilters - Final report.

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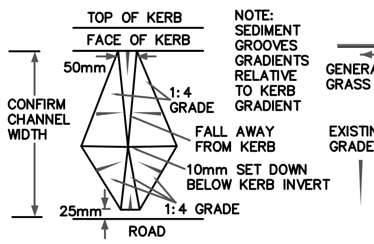
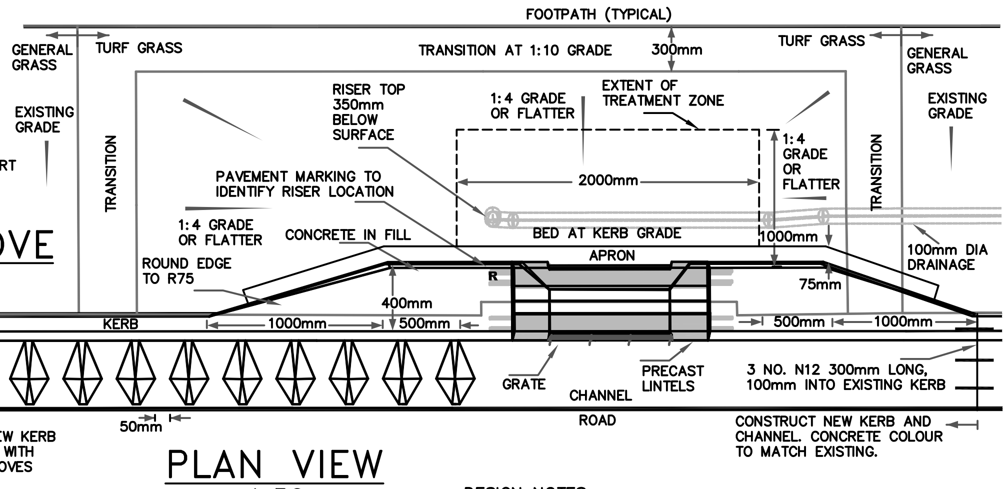


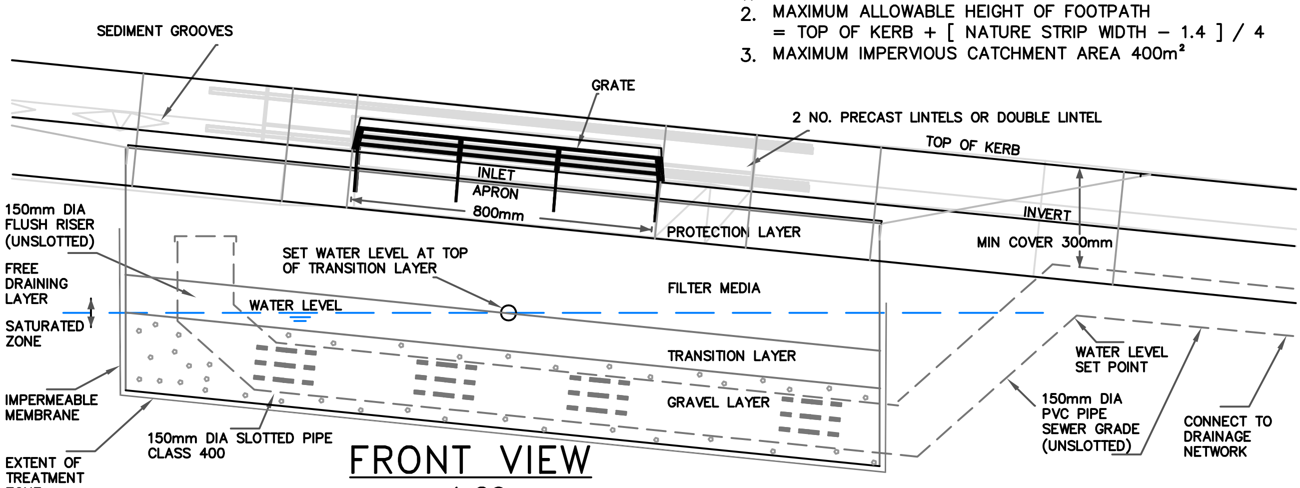
SEDIMENT GROOVE
1:20



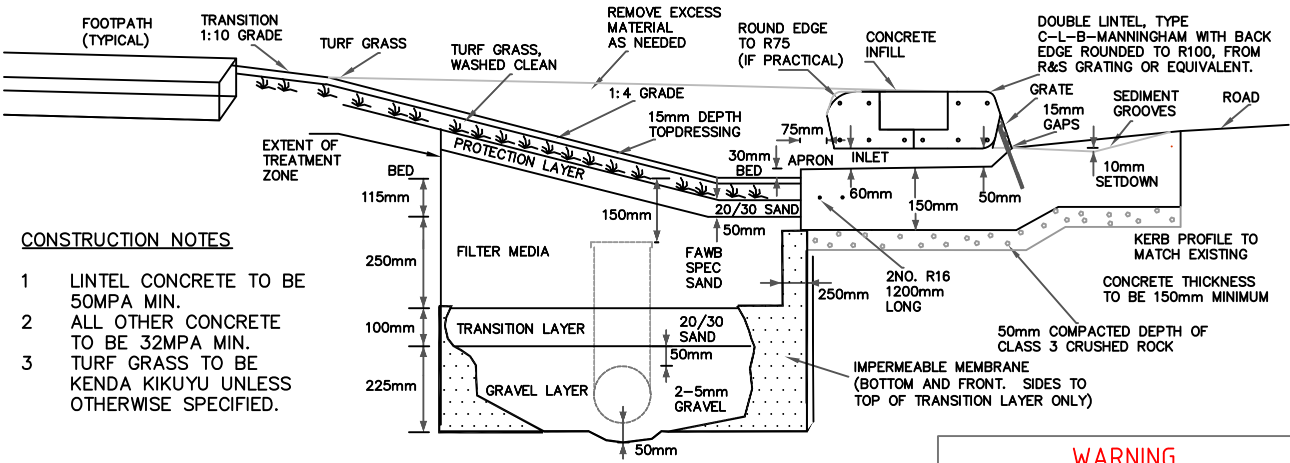
PLAN VIEW
1:50

DESIGN NOTES

1. UNSUITABLE FOR ROAD GRADIENTS EXCEEDING 1V:10H
2. MAXIMUM ALLOWABLE HEIGHT OF FOOTPATH
   = TOP OF KERB + [NATURE STRIP WIDTH − 1.4] / 4
3. MAXIMUM IMPERVIOUS CATCHMENT AREA 400m²



FRONT VIEW
1:20



CONSTRUCTION NOTES

1. LINTEL CONCRETE TO BE 50MPA MIN.
2. ALL OTHER CONCRETE TO BE 32MPA MIN.
3. TURF GRASS TO BE KENDA KIKUYU UNLESS OTHERWISE SPECIFIED.

TYPICAL SECTION
1:20

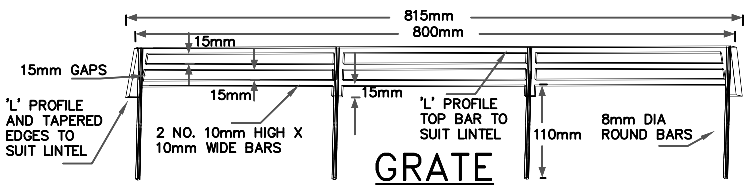
WARNING

BEWARE UNDERGROUND SERVICES

CONTACT MELBOURNE ONE CALL DIAL BEFORE YOU DIG ON 1100 AT LEAST 48 HOURS BEFORE COMMENCING EXCAVATIONS.

GRATE NOTES

1. GRATE TO BE CONSTRUCTED FROM 304 STAINLESS STEEL, TYPE TR-B-MANNINGHAM FROM R&S GRATING, OR AN APPROVED EQUIVALENT.
2. CONTRACTOR TO ENSURE THAT GRATE SIZE FITS LINTEL USED.



GRATE
1:10

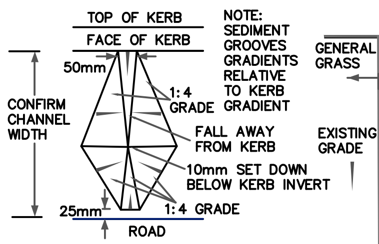
MANNINGHAM

STANDARD DRAWING

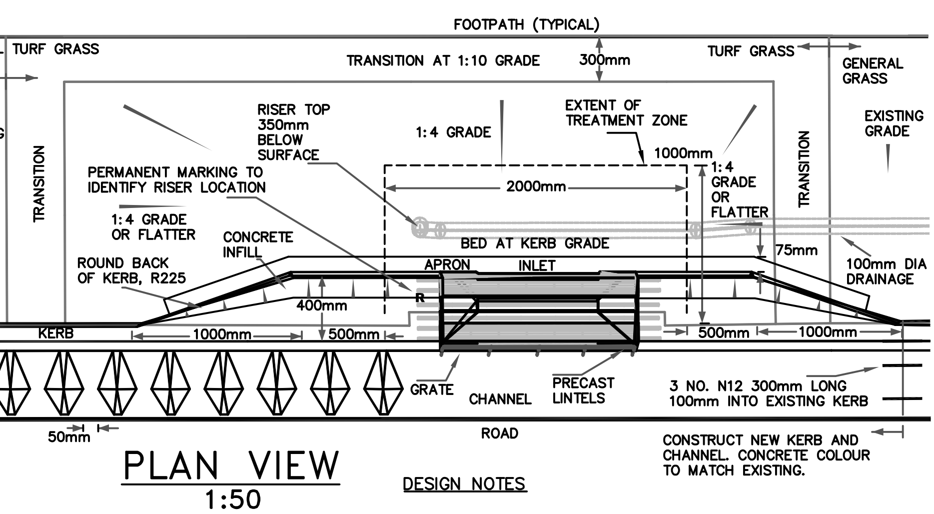
GRASSED ZAM-WSUD FOR BARRIER KERB

DATE OF ISSUE: 29/8/2018
SCALE (AT A4): AS SHOWN
DRAWN: S. BRINK

DWG No: S404



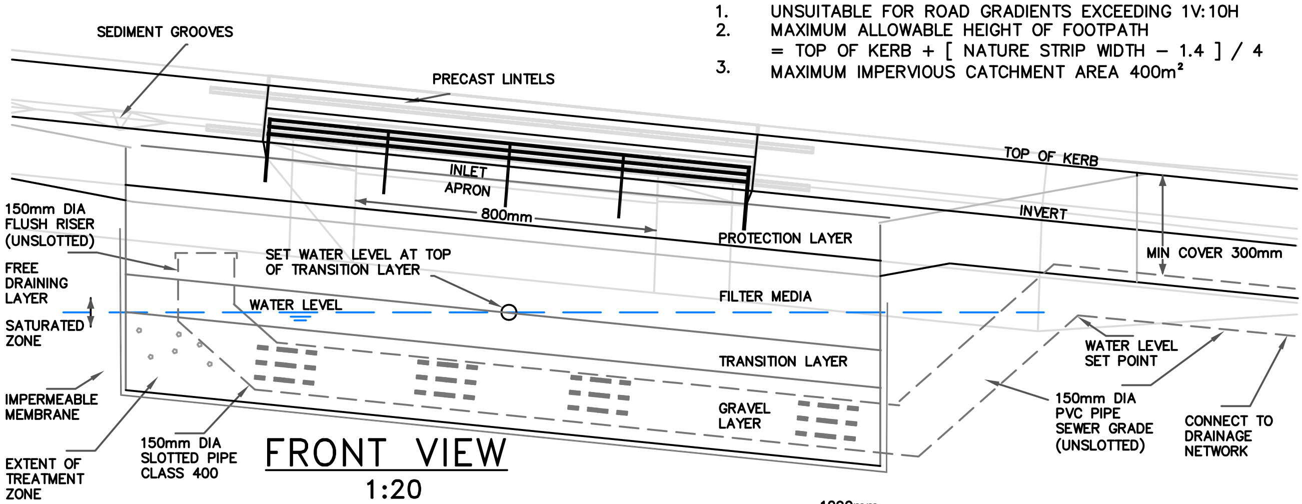
SEDIMENT GROOVE
1:20



PLAN VIEW
1:50

DESIGN NOTES

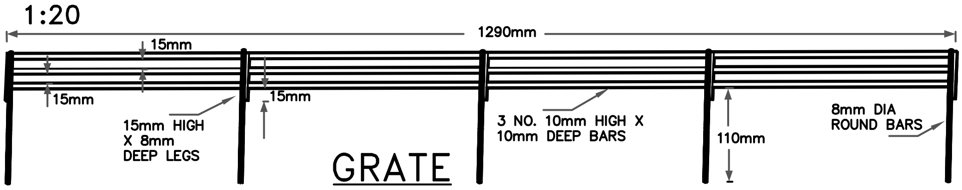
1. UNSUITABLE FOR ROAD GRADIENTS EXCEEDING 1V:10H
2. MAXIMUM ALLOWABLE HEIGHT OF FOOTPATH
   = TOP OF KERB + [NATURE STRIP WIDTH – 1.4] / 4
3. MAXIMUM IMPERVIOUS CATCHMENT AREA 400m^2



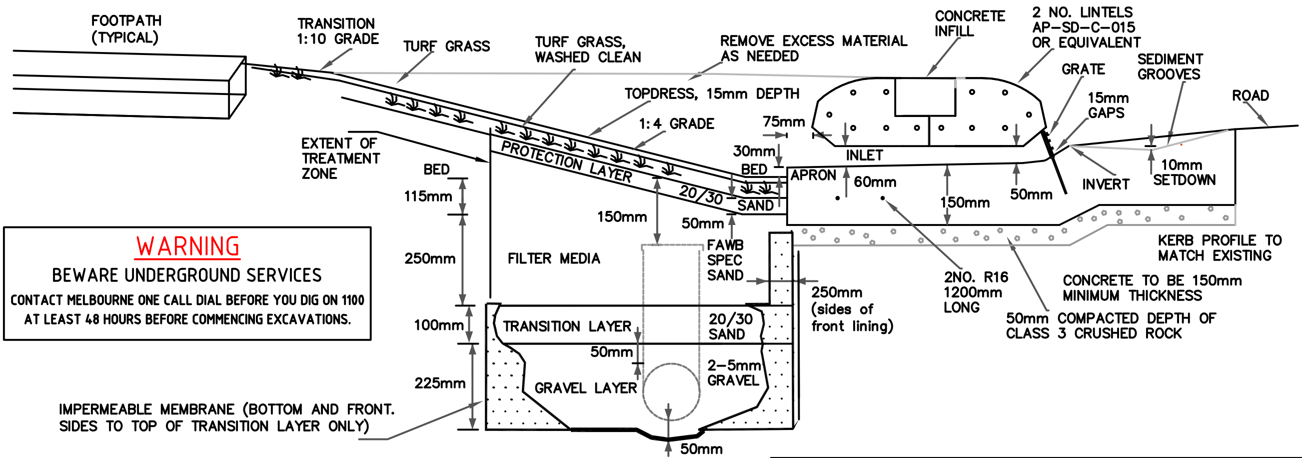
FRONT VIEW
1:20

GRATE NOTES

1. GRATE TO BE CONSTRUCTED FROM 304 STAINLESS STEEL
2. CONTRACTOR TO ENSURE THAT GRATE SIZE FITS LINTEL USED.



GRATE
1:10



WARNING

BEWARE UNDERGROUND SERVICES

CONTACT MELBOURNE ONE CALL DIAL BEFORE YOU DIG ON 1100 AT LEAST 48 HOURS BEFORE COMMENCING EXCAVATIONS.

TYPICAL SECTION
1:20

CONSTRUCTION NOTES

1. LINTEL CONCRETE TO BE 50MPA MIN.
2. ALL OTHER CONCRETE TO BE 32MPA MIN.
3. TURF GRASS TO BE KENDA KIKUYU UNLESS OTHERWISE SPECIFIED.
4. REFER TO MCC STANDARD DRAWING S206 FOR KERB AND CHANNEL PROFILE DETAILS.

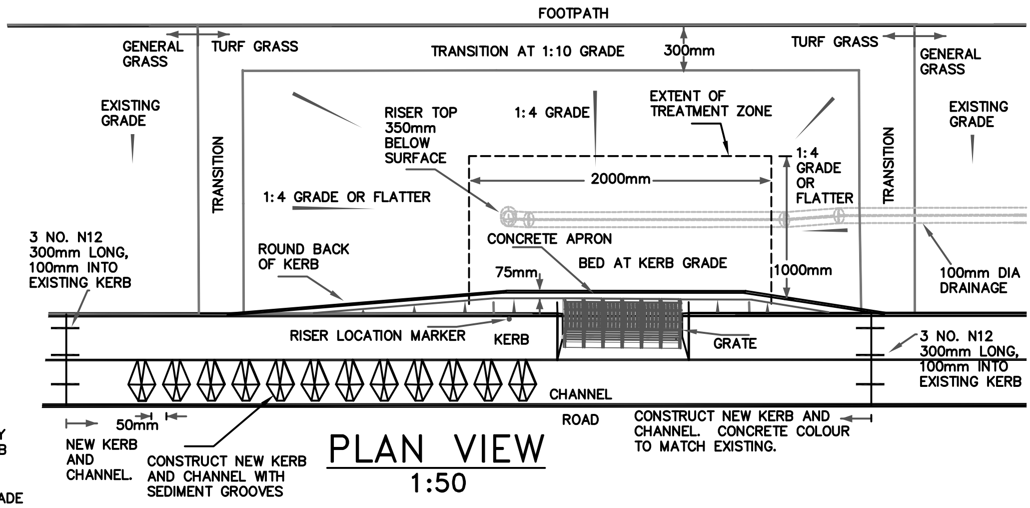
MANNINGHAM

STANDARD DRAWING

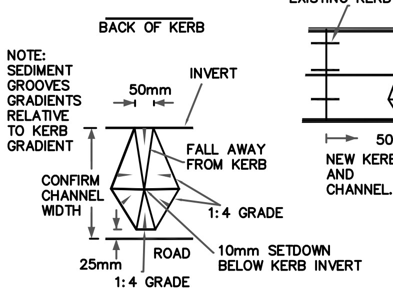
GRASSED ZAM–WSUD SEMI–MOUNTABLE KERB

DATE OF ISSUE: 29/8/2018
SCALE (AT A4): AS SHOWN
DRAWN: S. BRINK

DWG No: S405



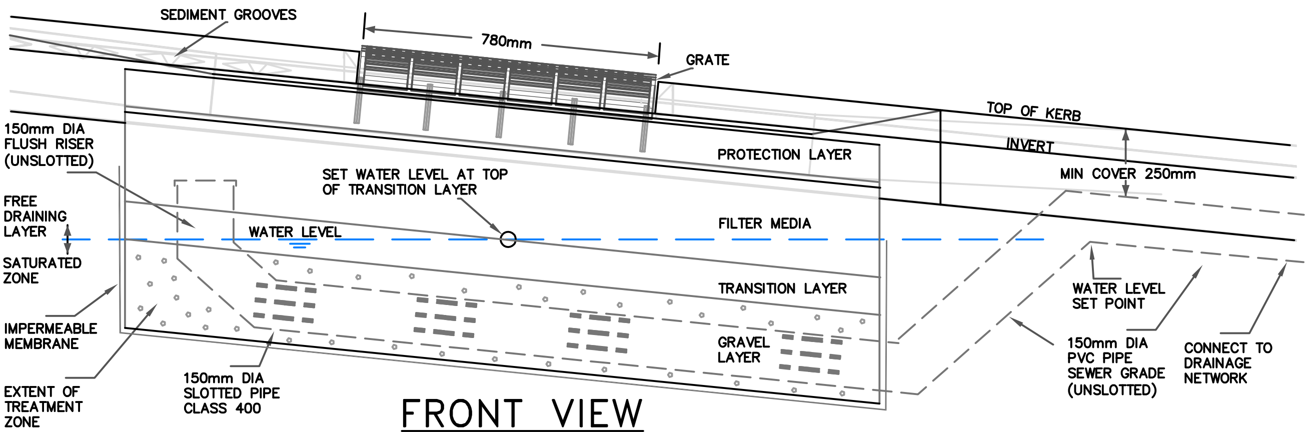
PLAN VIEW
1:50



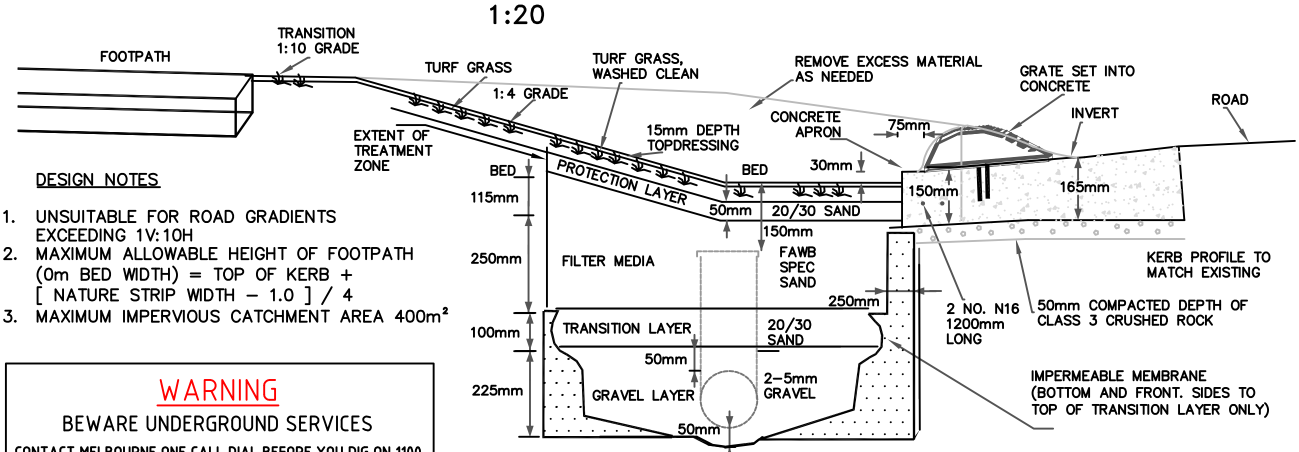
SEDIMENT GROOVE
1:20

CONSTRUCTION NOTES

1 CONCRETE TO BE 32MPA MIN.
2 TURF GRASS TO BE KENDA KIKUYU UNLESS OTHERWISE SPECIFIED.
3 REFER TO MCC STANDARD DRAWING S201 FOR KERB AND CHANNEL PROFILE DETAILS.



FRONT VIEW
1:20



DESIGN NOTES

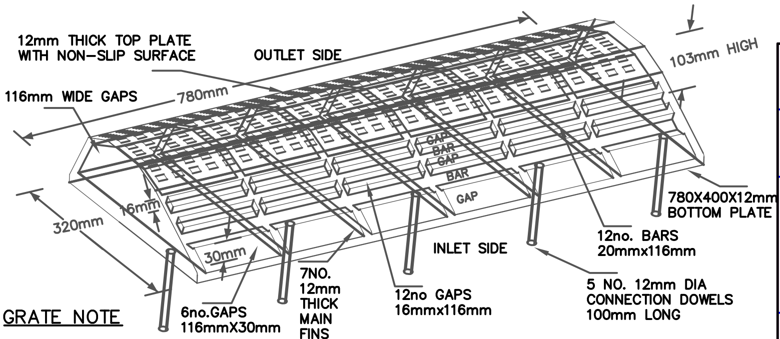
1. UNSUITABLE FOR ROAD GRADIENTS EXCEEDING 1V:10H
2. MAXIMUM ALLOWABLE HEIGHT OF FOOTPATH (0m BED WIDTH) = TOP OF KERB + [NATURE STRIP WIDTH – 1.0] / 4
3. MAXIMUM IMPERVIOUS CATCHMENT AREA 400m²

WARNING

BEWARE UNDERGROUND SERVICES

CONTACT MELBOURNE ONE CALL DIAL BEFORE YOU DIG ON 1100 AT LEAST 48 HOURS BEFORE COMMENCING EXCAVATIONS.

TYPICAL SECTION
1:20



GRATE NOTE

GRATE TO BE CONSTRUCTED FROM HOT DIP GALVANISED STEEL

GRATE DETAILS
1:10

MANNINGHAM

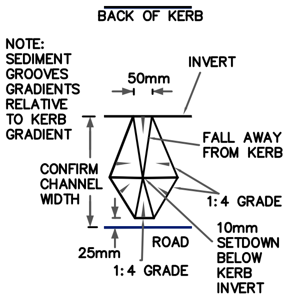
STANDARD DRAWING

GRASSED ZAM-WSUD FOR ROLLOVER KERB

DATE OF ISSUE: 29/8/2018
SCALE (AT A4): AS SHOWN
DRAWN: S. BRINK

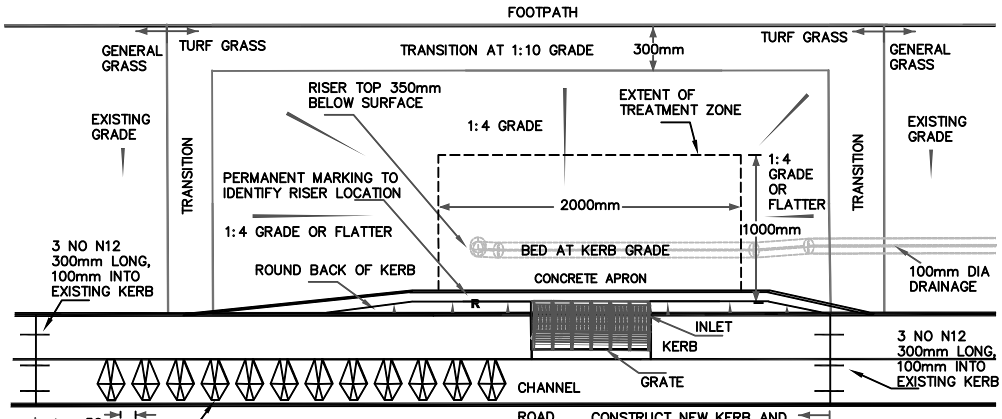
DWG No: S406

PRINTED: 30 August 2018 1:43 PM



SEDIMENT GROOVE

1:20



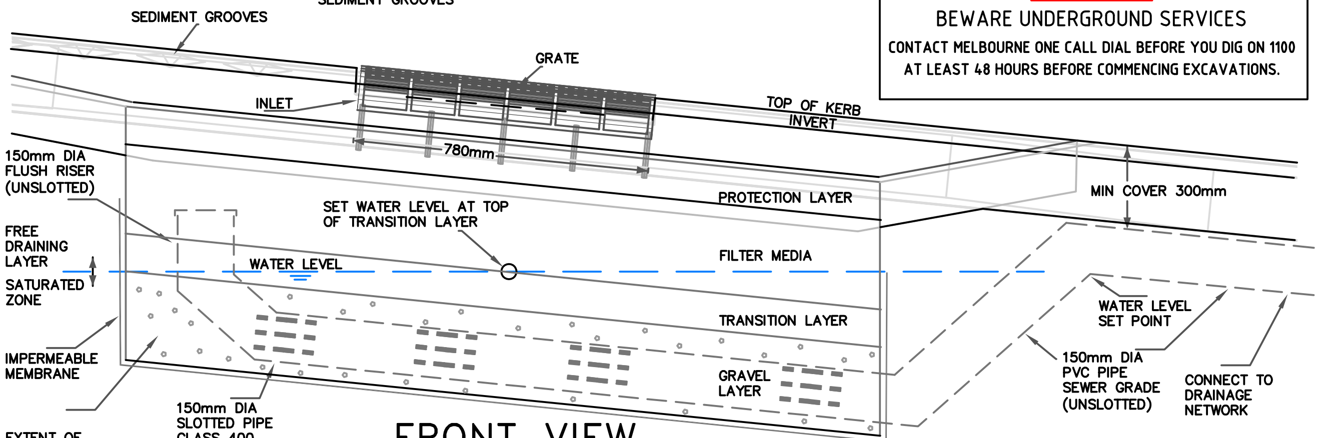
PLAN VIEW

1:50

WARNING

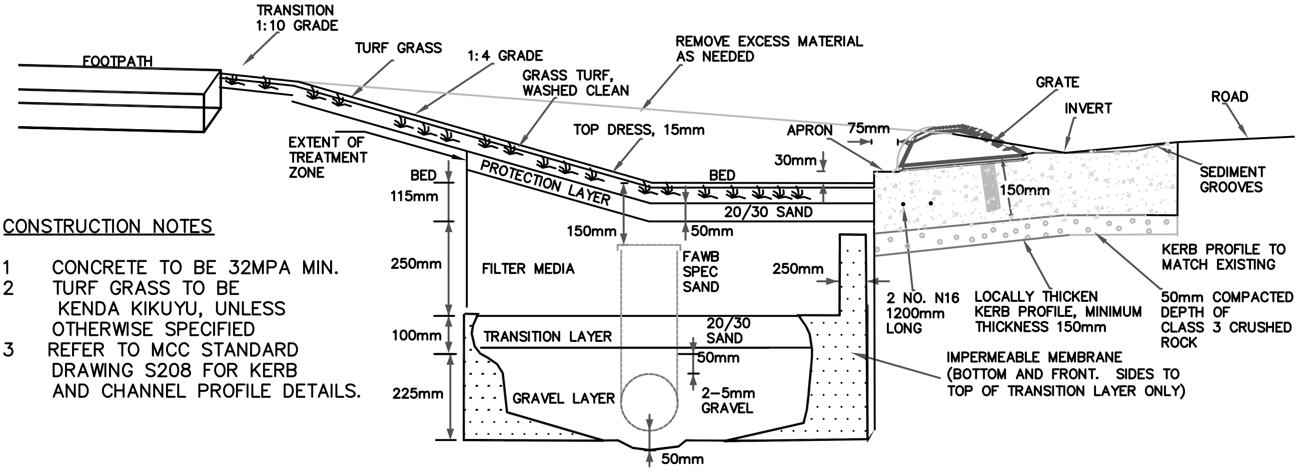
BEWARE UNDERGROUND SERVICES

CONTACT MELBOURNE ONE CALL DIAL BEFORE YOU DIG ON 1100 AT LEAST 48 HOURS BEFORE COMMENCING EXCAVATIONS.



FRONT VIEW

1:20



TYPICAL SECTION

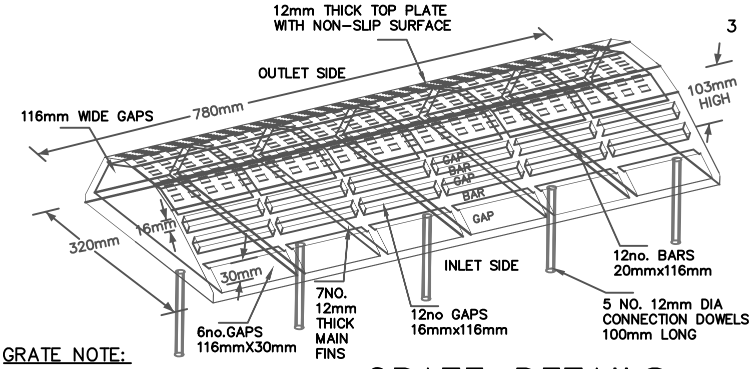
1:20

CONSTRUCTION NOTES

1. CONCRETE TO BE 32MPA MIN.
2. TURF GRASS TO BE KENDA KIKUYU, UNLESS OTHERWISE SPECIFIED
3. REFER TO MCC STANDARD DRAWING S208 FOR KERB AND CHANNEL PROFILE DETAILS.

DESIGN NOTES

1. UNSUITABLE FOR ROAD GRADIENTS EXCEEDING 1V:10H
2. MAXIMUM ALLOWABLE HEIGHT OF FOOTPATH (0m BED WIDTH) = TOP OF KERB + [NATURE STRIP WIDTH − 0.8] / 4
3. MAXIMUM IMPERVIOUS CATCHMENT AREA 400m²



GRATE NOTE:

TO BE CONSTRUCTED FROM HOT DIP GALVANISED STEEL

GRATE DETAILS

1:10

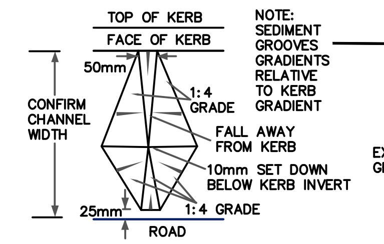
MANNINGHAM

STANDARD DRAWING

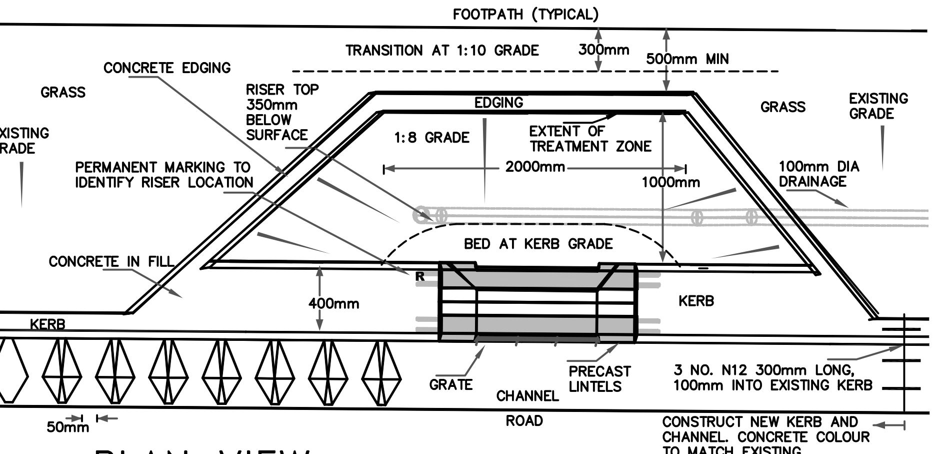
GRASSED ZAM–WSUD FOR MOUNTABLE KERB

DATE OF ISSUE: 29/8/2018
SCALE (AT A4): AS SHOWN
DRAWN: S. BRINK

DWG No: S407



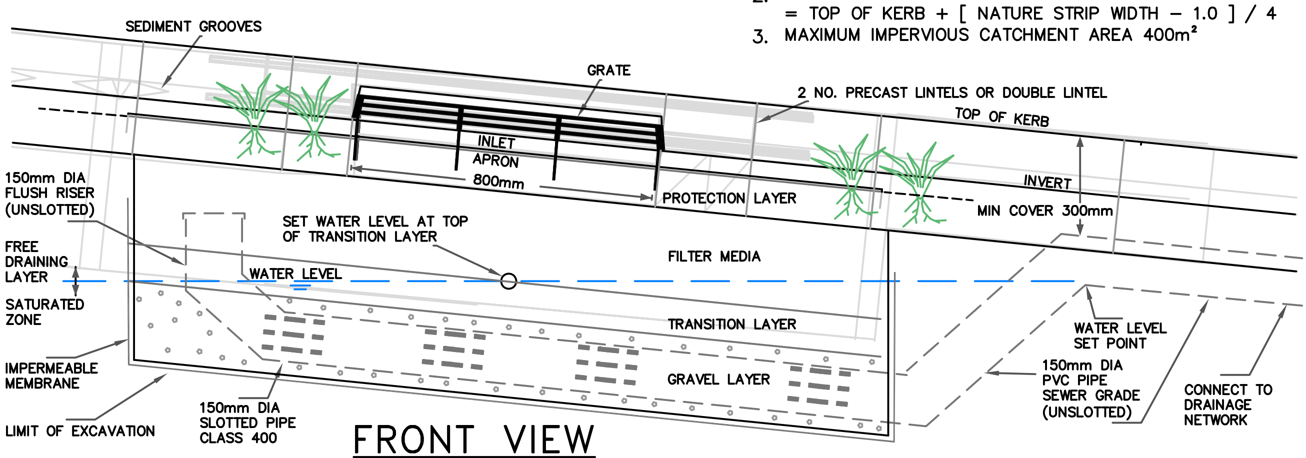
SEDIMENT GROOVE
1:20



PLAN VIEW
1:50

DESIGN NOTES

1. UNSUITABLE FOR ROAD GRADIENTS EXCEEDING 1V:10H
2. MAXIMUM ALLOWABLE HEIGHT OF FOOTPATH = TOP OF KERB + [NATURE STRIP WIDTH – 1.0] / 4
3. MAXIMUM IMPERVIOUS CATCHMENT AREA 400m²

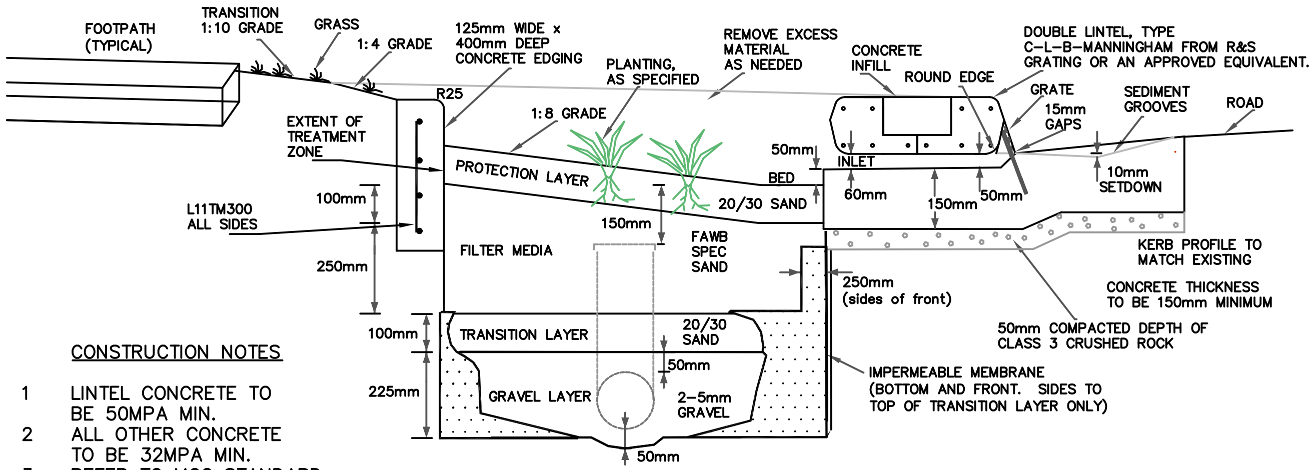


FRONT VIEW
1:20

GRATE NOTES

1. GRATE TO BE CONSTRUCTED FROM 304 STAINLESS STEEL, TYPE TR–B–MANNINGHAM FROM R&S GRATING OR AND APPROVED EQUIVALENT.
2. CONTRACTOR TO ENSURE THAT GRATE SIZE FITS LINTEL USED.

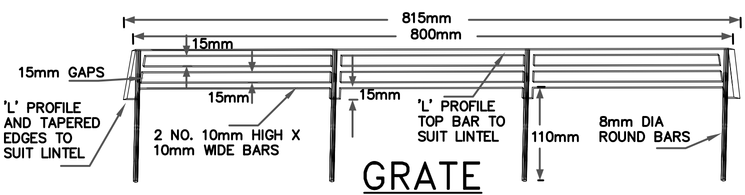
WARNING
BEWARE UNDERGROUND SERVICES
CONTACT MELBOURNE ONE CALL DIAL BEFORE YOU DIG ON 1100
AT LEAST 48 HOURS BEFORE COMMENCING EXCAVATIONS.



CONSTRUCTION NOTES

1. LINTEL CONCRETE TO BE 50MPA MIN.
2. ALL OTHER CONCRETE TO BE 32MPA MIN.
3. REFER TO MCC STANDARD DRAWINGS S203 AND S212 FOR KERB AND CHANNEL PROFILE DETAILS.

TYPICAL SECTION
1:20



GRATE
1:10

MANNINGHAM

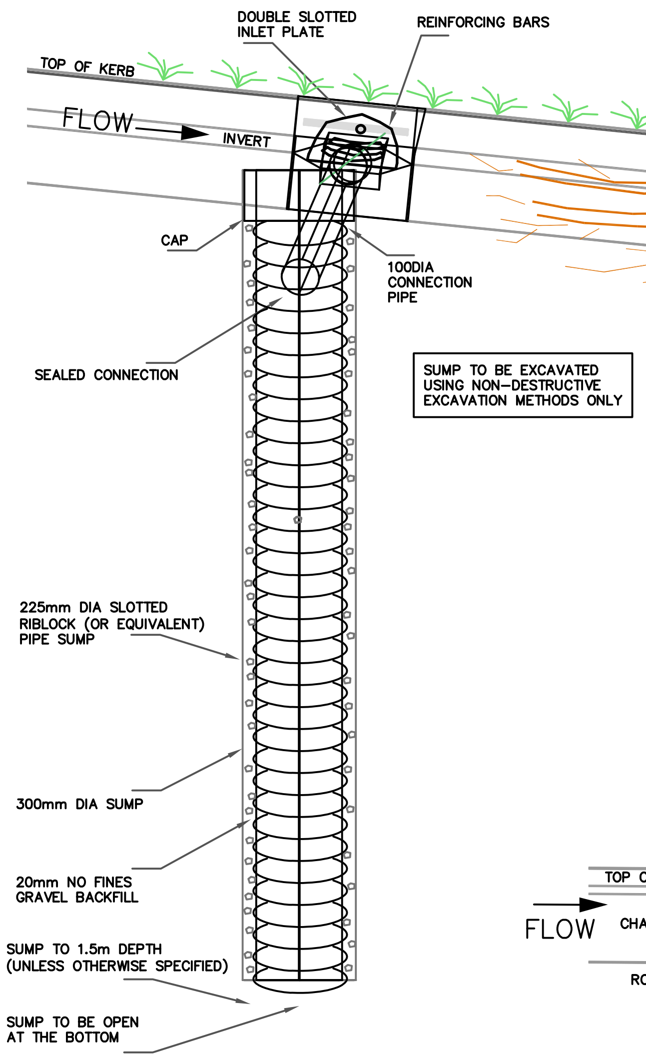
STANDARD DRAWING

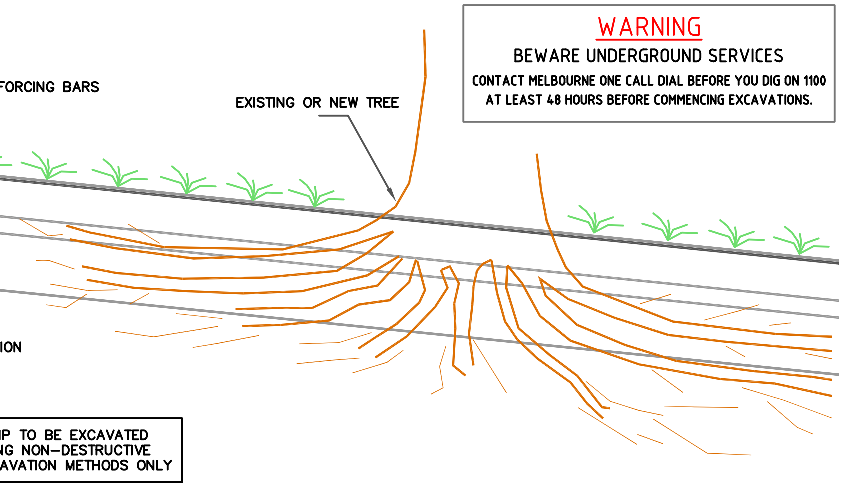
VEGETATED ZAM–WSUD FOR BARRIER KERB

DATE OF ISSUE: 29/8/2018
SCALE (AT A4): AS SHOWN
DRAWN: S. BRINK

DWG No: S408

PRINTED: 30 August 2018 1:44 PM



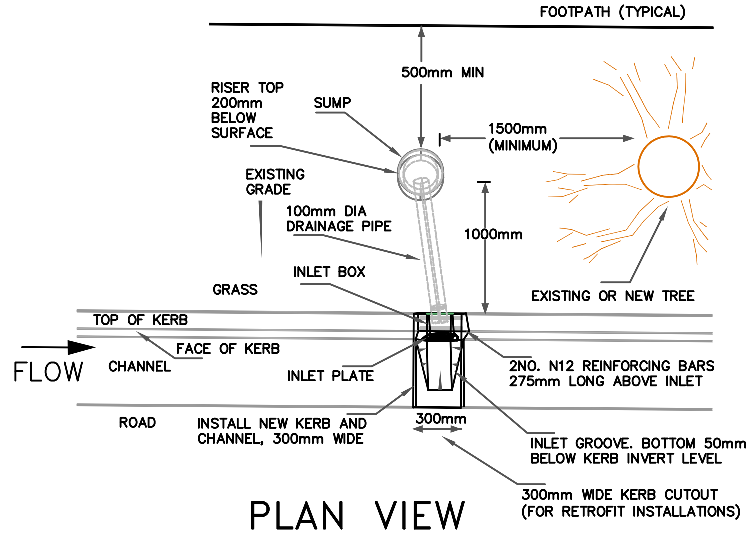


WARNING
BEWARE UNDERGROUND SERVICES
CONTACT MELBOURNE ONE CALL DIAL BEFORE YOU DIG ON 1100 AT LEAST 48 HOURS BEFORE COMMENCING EXCAVATIONS.

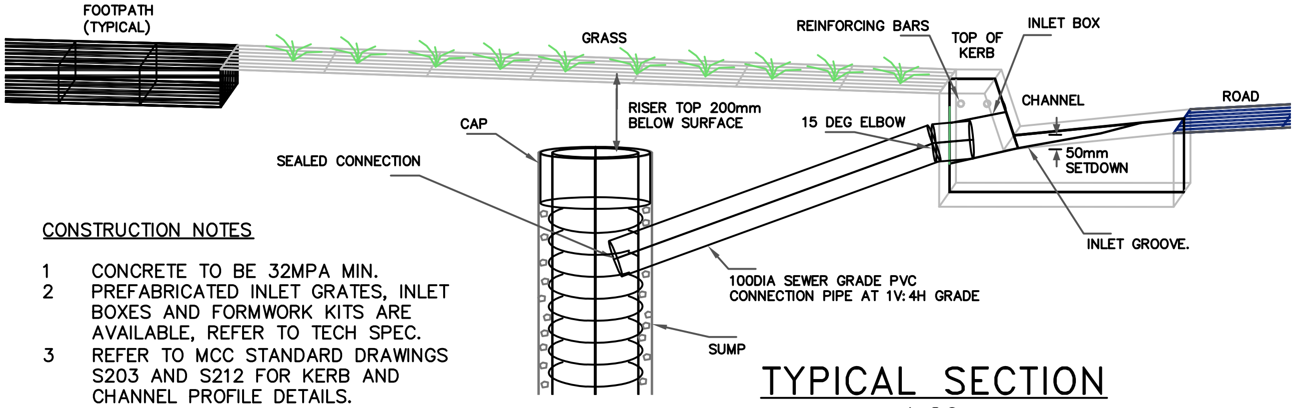
FRONT VIEW
1:20

DESIGN NOTES

1. SUITABLE FOR IMPERVIOUS CATCHMENT AREAS UP TO 100m²



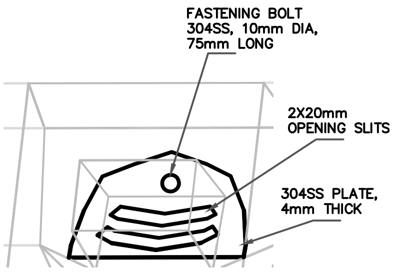
PLAN VIEW
1:50



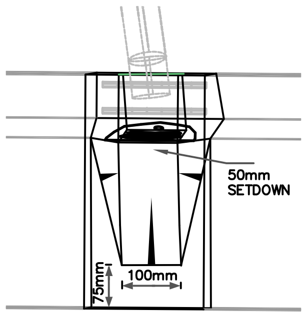
TYPICAL SECTION
1:20

CONSTRUCTION NOTES

1 CONCRETE TO BE 32MPA MIN.
2 PREFABRICATED INLET GRATES, INLET BOXES AND FORMWORK KITS ARE AVAILABLE, REFER TO TECH SPEC.
3 REFER TO MCC STANDARD DRAWINGS S203 AND S212 FOR KERB AND CHANNEL PROFILE DETAILS.



GRATE
1:10



SEDIMENT GROOVE
1:20

MANNINGHAM

STANDARD DRAWING

TREENET
FOR BARRIER KERB

DATE OF ISSUE: 29/8/2018 SCALE (AT A4): AS SHOWN DRAWN: S. BRINK	DWG No: S409

PRINTED: 30 August 2018 1:15 PM

ZAM-WSUD Technical Specifications

Zero Additional Maintenance Water Sensitive Urban Design
with no ongoing maintenance requirements for asset owners

Interpreter service
9840 9355
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Italiano | عربي | فارسی

Melbourne Water

CRC for Water Sensitive Cities

MANNINGHAM

TABLE OF CONTENTS

LIST OF FIGURES

MANNINGHAM

1. ZAM-WSUD Biofilters

1.1. General

Zero Additional Maintenance Water Sensitive Urban Design (ZAM-WSUD) installations shall be constructed in accordance with these technical specifications, except where otherwise noted on the design plans or contract documentation.

1.2. ZAM-WSUD Filter Media Profile

The filter media profile shall be in accordance with the following schematics:

Grassed installations

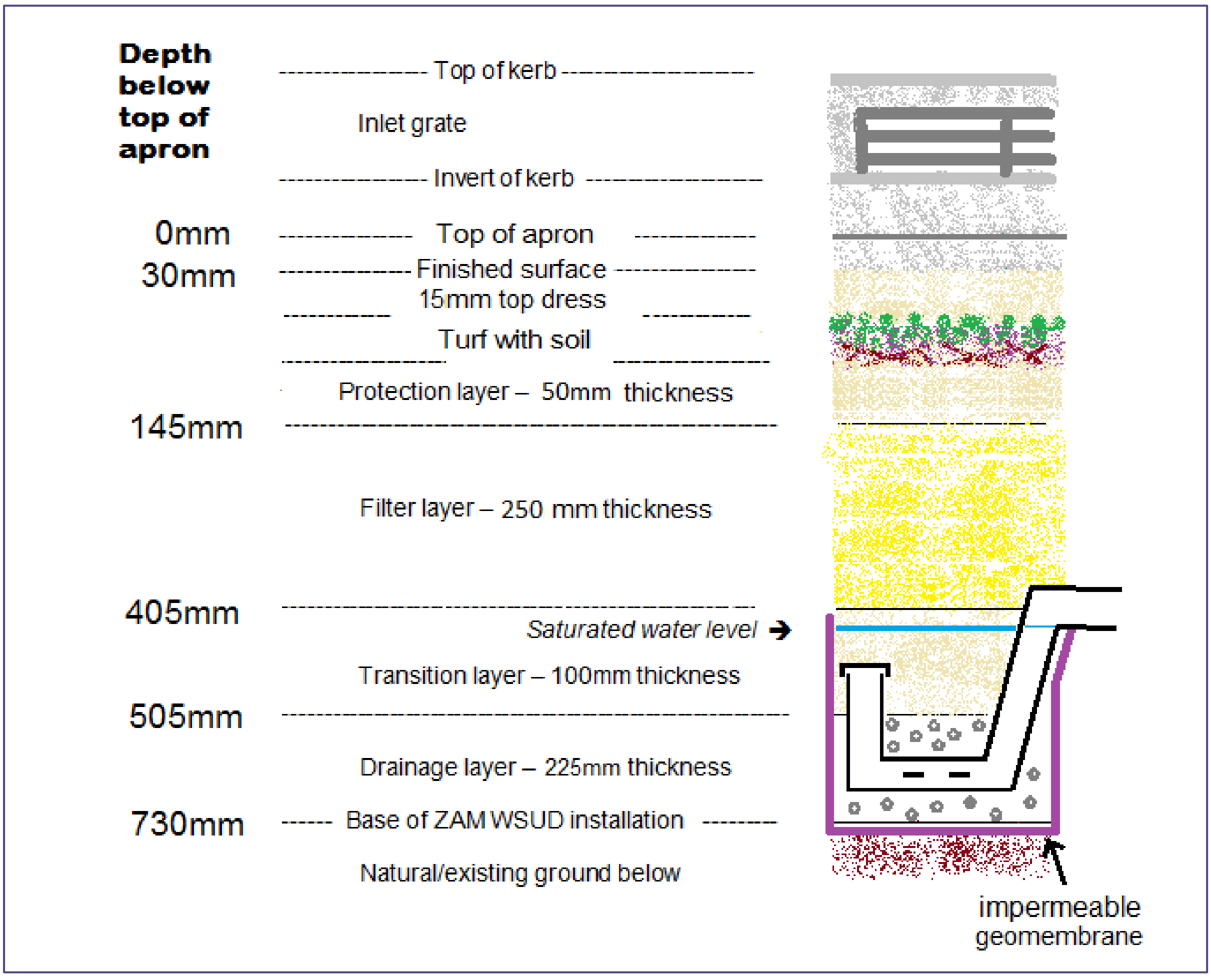

Figure 1 - Grassed ZAM-WSUD installation filter media profile

Vegetated Installations

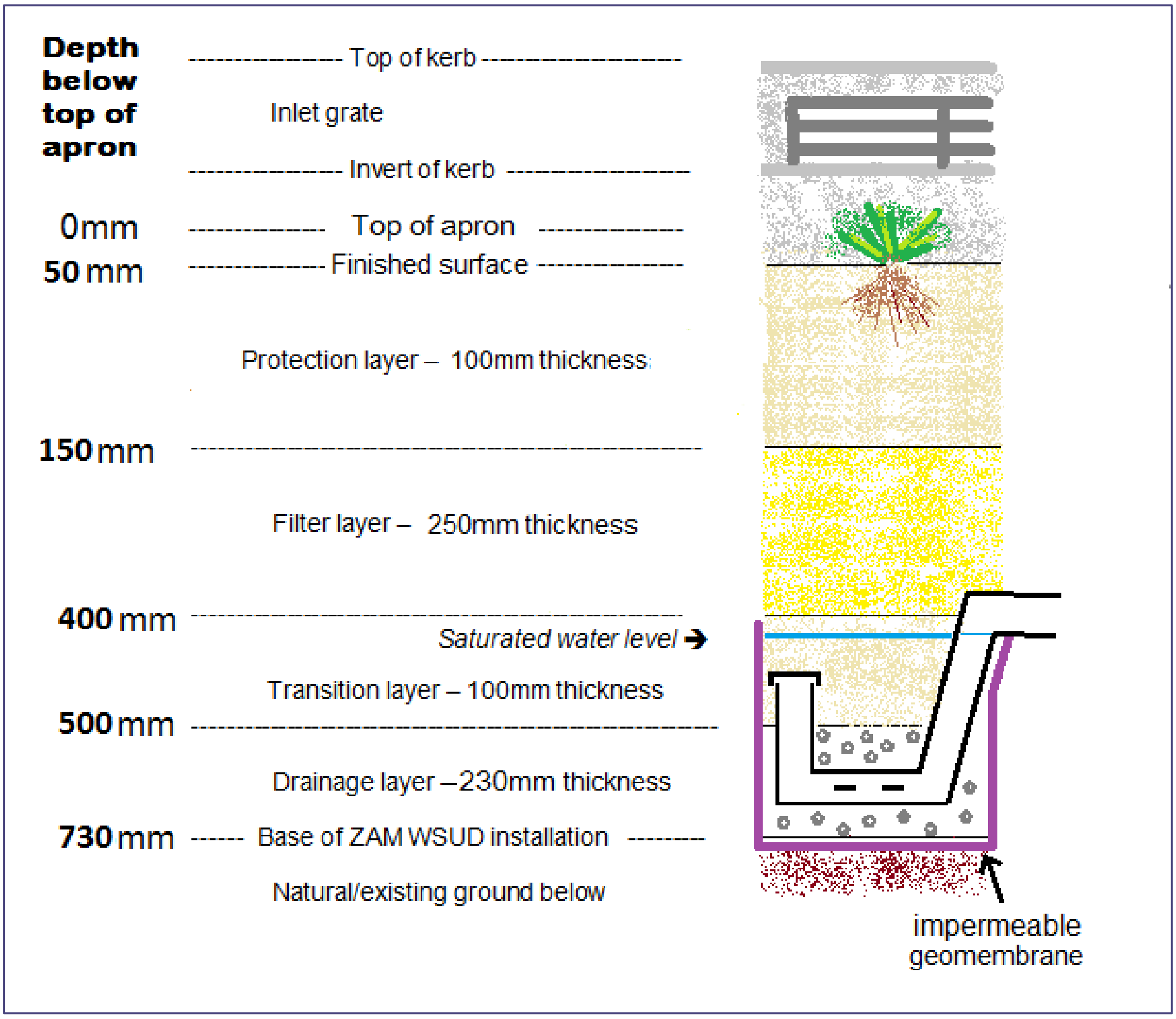

Figure 2 - Vegetated ZAM-WSUD installation filter media profile

For landscaped ZAM-WSUD installations featuring larger vegetation such as shrubs over 1.0m in height and/or small trees, the depth of the filter layer and/or transition layer shall be increased to provide additional volume for plant roots.

1.3. Lintel Details

Lintels shall be reinforced concrete and prefabricated. Concrete for precast lintels shall be 50MPa minimum. Concrete lintel shall be connected to kerbing each side using reinforcing bars, as shown on standard drawings.

1.4. Inlet Grates

Inlet grates for barrier and SM2 kerb shall be constructed from 304 stainless steel and shall be in accordance with the standard drawings. Any bolts or fixings in contact with the grate must also be 304 stainless steel (or a similar compatible stainless steel).

Suitable product: R&S Grating – Trash Rack - TR-B-MANNINGHAM

Inlet grates for rollover and mountable kerb shall be 304 stainless steel or hot dip galvanized steel and shall be in accordance with the standard drawings. Any bolts or fixings in contact with the grate must be made of the same material.

Suitable product: R&S Grating - Trash Rack - TR-SM-MANNINGHAM

Note: SM2 kerb requires a TR-B grate not a TR-SM grate!!!

Steel grates other that the above products must be inspected and approved by the superintendent/ superintendent's representative prior to installation.

1.5. Turf

For grassed ZAM-WSUD installations, turf is to be supplied and installed by the contractor as sod. Sod must be grown in a high permeability soil such as a sand or sandy loam. Turf sod shall be approximately 50mm thick.

Figure 3 - Turf sod rolls

Suitable Products

Site Characteristics	Suitable Grass Species
Sunny	**Kikuyu**, male sterile varieties - Kenda, Village Green **Couch** - Santa Ana
High pedestrian traffic	**Kikuyu**, male sterile varieties - Kenda, Village Green
Part Shade	**Zoysia** - Empire
Very shady sites with moist soils	**Soft Leaf Buffalo** – Palmetto SS100 (Victoria, Tasmania, Canberra and elevated areas in NSW) **Soft Leaf Buffalo** – Sapphire B12 (Queensland, Western Australia, lowland NSW)
Environmentally sensitive areas	**Zoysia** - Nara Native **Soft Leaf Buffalo** – Palmetto SS100

It is recommended that the contractor hire turf suppliers as early as possible to ensure that the turf is available at the required time.

As unplanted turf, survival time is relatively short so contractors *must* water turf immediately upon delivery and must plant turf within 24 hours of delivery to best ensure survival.

Turf must be well watered immediately after planting and every second day for the first six weeks after planting unless rainfall is regular and adequate to saturate soils. If conditions are dry and warm dry, watering every day for the first ten days is recommended.

Grass needs to be thoroughly watered. Minimum watering volumes can be determined by Bureau of Meteorology evapotranspiration (ETo) data from the closest weather station available at www.bom.gov.au/watl/eto/ Watering volumes must exceed net rainfall deficit (Net = Rainfall – ETo).

Mid-autumn planting is recommended to allow maximum time for establishment before the ensuing summer. If planting is done in late spring or early summer, turf must be watered regularly for the first three months at least.

Watering is the contractor's responsibility, unless otherwise specified. The contractor shall be responsible for replacement of any areas of turf that do not survive because of inadequate watering during establishment.

1.6. Plants

In accordance with recommendations in *Adoption Guidelines for Stormwater Biofiltration Systems – Summary Report*, (Co-operative Research Centre for Water Sensitive Cities, 2016), at least 50% of the vegetation cover in ZAM-WSUD installations shall be with plants that have a confirmed high nutrient uptake capacity. The remaining plants can be selected for other attributes such as aesthetics, amenity and/or local biodiversity.

Plant species that have been confirmed as having high nitrogen uptake rates that maybe suitable for vegetated ZAM-WSUD installations, subject to site specific considerations, include:

Species	Origin	Height	Notes
Baumea juncea **Bare Twigrush**	Southern coastal	0.2m-1.2m	Salt tolerant Full sun of semi shade
Baumea rubiginosa **Soft Twig Rush**	Widespread	0.3m-1.2m	Damp areas Full or part sun
Carex appressa **Tall sedge**	Widespread	to 1m	Very robust High Phosphorous uptake also Supports native fauna Sharp leaves
Carex tereticaulis **Rush sedge**	Widespread	to 1m	Spiky, can poke eyes Full sun
Ficinia nodosa **Knotted Club Rush**	Widespread	to 1m	Spiky, can poke eyes Fast growing
Goodenia ovata **Hop goodenia**	Southeast Australia	to 2m	Quick growing Can look weedy

Species	Origin	Height	Notes
			Prefers part shade
Juncus amabilis **Gentle rush**	Southern Australia	to 1.2m	Spiky Full or part sun
Juncus flavidus **Rush**	Widespread, inland	to 1m	Prefers wet conditions
Juncus pallidus **Grey soft rush or pale rush**	East Australia	0.7m to 1.4m	Spiky Prefers wet conditions Full or part sun
Juncus subsecundus **Finger rush**	Widespread	to 1m	Full or part sun
Melaleuca incana **Grey Honey Myrtle**	Southwest Western Australia	2m to 3m	Suitable for east coast also High Phosphorous uptake also Full sun Salt tolerant
Melaleuca ericifolia **Swamp Paperbark**	Southeast Australia	to 9m	Frost tolerant Drought tolerant once established Full or part sun
Melaleuca lateritia **Robin Red-breast Bush**	Southwest Western Australia	to 2m (generally) to 1.5m (ACT)	Shape can benefit from pruning Prefers damp conditions Full sun preferred

Reference: Adapted from *Adoption Guidelines for Stormwater Biofiltration Systems – Summary Report* (Co-operative Research Centre for Water Sensitive Cities, 2016)

Plants shall be watered immediately after installation. Watering is the contractor's responsibility, unless otherwise specified. Autumn planting is recommended to be best allow establishment before the ensuing summer.

1.7. Impermeable Membrane

ZAM-WSUD systems must be constructed with an effective saturated zone to improve drought tolerance.

A geofabric impermeable membrane shall be installed to create a saturated zone, unless the subsoils exposed during excavation are significantly impermeable and not subject to seasonal cracking, such that they can provide an effective impermeable layer in both wet and dry conditions.

Suitable products: A 100 micron (minimum) thick geofabric impermeable membrane, EDPM or similar.

The membrane shall be installed:

- At the base and on all sides of the ZAM-WSUD installation up to or above the bottom of the filter media layer to form the saturated zone, and

- On any side of the ZAM-WSUD asset facing a road pavement up to the bottom of kerb level, including on adjacent sides to a minimum of 0.25m width.

Refer to standard drawings for details.

1.8. Protection Layer

The protection later is be 20/30 sand with a hydraulic conductivity between 1,000mm/hour and 1,600mm/hour ameliorated with organic matter, fertiliser and trace elements.

Suitable products - Burdetts - 20/30 sand (preferred) Contact: (03) 9789 8266 Andrew Burdett

Protection layer sand is to be placed both prior to turf placement and as top dressing after turf is placed. Refer to cross sections for depths.

Figure 4 - 20/30 Sand Top Dressing for a Landscaped ZAM-WSUD Installation

Burdett's – 20/30 Sand Particle Distribution

Sediment	Particle Size (mm)	Percentage
Fine Gravel	2.0	2
Very Course Sand	1.0	13
Coarse Sand	0.5	61
Medium Sand	0.25	21
Fine Sand	0.15	1
Very Fine Sand	0.05	2
Silt and Clay	<0.05	Trace
Hydraulic Conductivity Drainage	mm/hr	1316
Texture		Off white sand

Amelioration (to be mixed into the protection layer)

Constituent	**Quantity** g/m² of biofilter area
Granulated poultry manure fines	500
Superphosphate	20
Magnesium sulphate	30
Potassium sulphate	20
Trace element mix	10
Fertiliser N:P:K (16:4:14) ***(nitrogen: phosphorous: potassium)***	40
Lime	200

1.9. Filter Layer

ZAM-WSUD installations require an effective filter media layer with a moderate hydraulic conductivity (200-300mm per hour) that both allows an adequate flow rate and sufficient time for nutrient absorption and plant root uptake.

The filter media layer must have a particle size distribution that complies with the FAWB specification, as follows:

FAWB Specification

Description	Allowable Proportion	Particle Size
Clay/silt	<3%	<0.05mm
Very fine sand	5-10%	0.05-0.15mm
Fine sand	10-25%	0.15-0.25mm
Medium to Course sand	60-70%	0.25-1.0mm
Course sand	7-10%	1.0-2.0mm
Fine gravel	<3%	2.0-3.4mm
Other gravel	0%	>3.4mm

Figure 5 - FAWB Specification - Particle Size Distribution

Suitable Products: Daisys – Bio Drain Filter Sand

	Bio Drain Filter Sand
pH (1:5 water)	5.6
Electrical conductivity (mS/cm)	0.012
Total Salts (ppm)	36
Particle Size (mm)	
Fine Gravel (2.0mm)	1
Very Coarse Sand (1.0mm)	7
Coarse Sand (0.5mm)	21
Medium Sand (0.25mm)	39
Fine Sand (0.15mm)	23
Very Fine Sand (0.05)	7
Silt and Clay (<0.05mm)	2
Hydraulic Conductivity (mm/hr) Drainage	297

Figure 6 - Daisys - Bio Drain Filter Sand - Particle Size Distribution

1.10. Transition Layer

ZAM-WSUD systems require a transition layer between the filter media and drainage layer to prevent mobilisation of finer sands into the drainage layer.

The transition layer shall be a 20/30 sand with a hydraulic conductivity of at least 1,000 mm/hour.

Suitable products: Burdetts - 20/30 sand. Contact: (03) 9789 8266 Andrew Burdett. Refer to 20/30 particle size distribution information in section 1.8.

1.11. Drainage Layer

A drainage layer is required at the base of ZAM-WSUD systems around the slotted ag pipe to allow ease of water flow into the slotted ag outlet pipe and to prevent sand entry into this pipe.

The drainage layer shall be no fines gravel, ie 2.5mm nominal diameter screenings.

Screenings shall generally range in size between approximately 1.5mm and 4mm diameter.

1.12. Finished Surface Profile

The contractor shall ensure that the finished surface profile of grassed areas are suitable for the mower type used to mow the grass at the location of the installation.

Mower type	Mowing width	Gradient
Hand	0.5m	1V:4H or flatter
Small Ride-on	1.1m	1V:5H or flatter
Kabota	2.0m	1V:6H or flatter

Grade transitions are to be smooth enough to ensure that the mowers do not bottom out and cause damage to grass and/or mowers.

To ensure pedestrian safety, cross fall within 300mm of footpaths is not to be steeper than 1V:10H gradient.

1.13. Plumbing

Drainage pipes shall be 150mm diameter PVC, sewer grade. Slots are to be provided for the section of pipe at the base of the ZAM-WSUD installation only. Slots are to be 1mm width and 100mm long. A minimum of 16 slots are to be provided per metre.

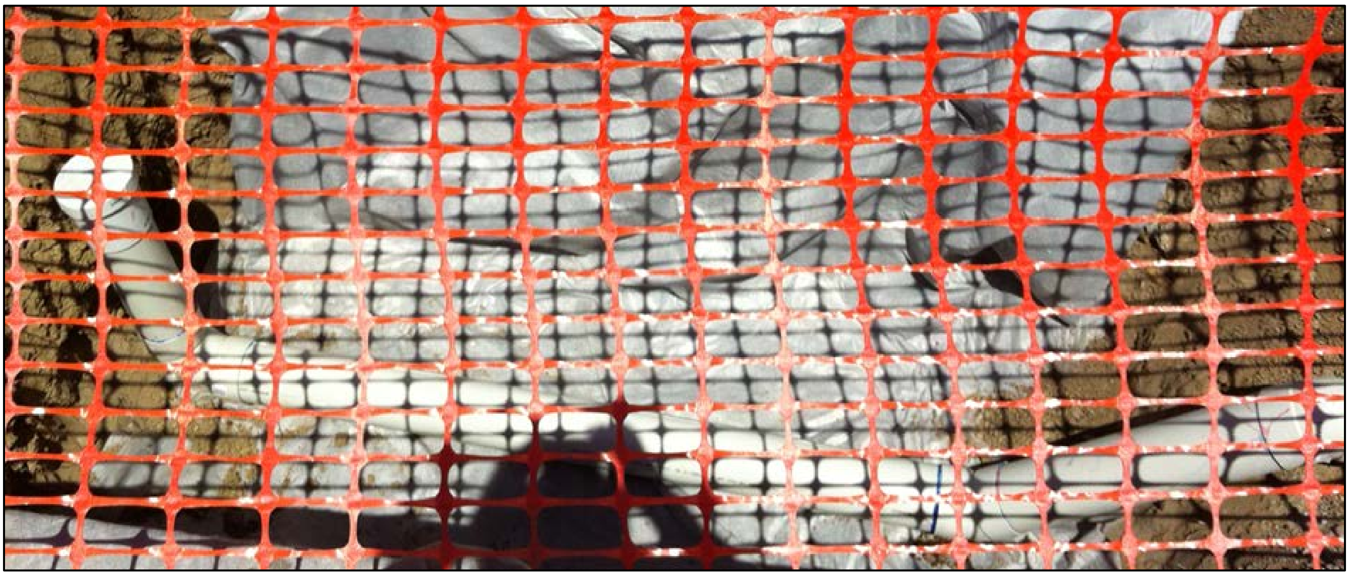

Figure 7 - Slotted ag pipe for ZAM-WSUD installation, including flush riser with cap (left) and outlet riser (right)

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1.14. Concrete Apron

For grassed ZAM-WSUD installations an extended concrete apron shall be provided beyond the back of the double lintel to allow maintenance of grass directly behind the back of kerb without requiring the use of an edge trimmer. The concrete apron extension shall be 75mm wide minimum, 150mm thickness, and shall extend the full width of the ZAM-WSUD set down area, and at least half way up the batter slopes on each side.

A concrete apron extension is not required for vegetated installations, but can be used to provide separation between the filter media area and the pavement subbase.

Figure 8 - Concrete apron on a grassed ZAM-WSUD installation

1.15. Sediment Grooves

Sediment grooves shall be constructed in the kerb channel just upstream of a ZAM-WSUD inlet to reduce sediment and suspended solids loads entering the filter area. Sediments shall be constructed with a 10mm ponding depth to assist with suspended solids deposition.

For typical urban catchments with a 6 week street sweeper frequency, sediment grooves shall be provided as follows:

Catchment Size	Number of Sediment Grooves
Up to 150m^2	6 no.
> 150m^2	12 no.

Kerb channel shall be thickened to 150mm at the location sediment groove location to minimise the risk of cracking. Sediment grooves shall be shaped so that they are free draining and do not allow water to pond at the base of the grooves.

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Figure 9 - Sediment grooves with trapped sediment

1.16. ZAM-WSUD Construction Inspections

The contractor shall provide the superintendent/superintendent's representative with the opportunity to inspect works at each site at the following stages:

- Set out.
- Subsoil inspection (for installations without impermeable membranes).
- Completion of impermeable membrane placement and plumbing works, prior to placement of gravel drainage material.
- Completion of placement of subsequent layers.

A minimum of 24 hours' notice is to be given by the contractor prior to any inspections.

The contractor shall take photos at the completion of each layer, including showing evidence of the finished level of the top of each layer using a tape measure of similar. Photos shall be provided to the superintendent/superintendent's representative.

During construction the superintendent/superintendent's representative may deem that photographic evidence is satisfactory for some hold points.

1.17. Site Clean Up and Vegetation Establishment

Contractors are responsible for restoration and cleanup of all sites at the completion of construction. This must be done to the satisfaction of the superintendent/superintendent's representative.

As previously mentioned, the contactor is responsible for watering of turf and/or plants during the establishment period, ie for the first 6 weeks after planting.

The contractor shall replace any turf and/or plants in poor condition at the end of the establishment period and shall water any replacement plants during their establishment. The contractor shall also regularly inspect sites and promptly rectify any subsidence issues by backfilling with 20/30 sand.

2. TreeNet Inlets

2.1. Setout

TreeNet sumps are to be located on the upstream side of new or existing trees. For new trees, sumps are to be located 1.5m from the trunk. For existing trees, sumps are to be located just inside the extent of the canopy, where practical, subject to construction methodology.

Sumps are to be located a minimum of 1m from the back of kerb, typically midway between the footpath and roadway, subject to underground service locations. This ensure that any risk of water movement into road pavement subbase is minimised.

2.2. Excavation

Non-destructive excavation methods are to be used for both TreeNet sump and inlet pipe installation.

2.3. Materials

The TreeNet sump is to be a slotted 225mm dia steel reinforced polyethylene pipe, corrugated and slotted.

Suitable Products: Riblock www.rocla.com.au/Plastream-Slotted-Pipe.php

Inlet pipe is to 90mm sewer grade PVC pipe.

Sump cap is to be sewer grade PVC, and is to be at a depth of 200mm below finished surface level.

All PVC jointing is to be solvent welded with section overlaps to be 40mm minimum on all sides.

The connection between the inlet pipe and the sump is to fully sealed with a a flexible high strength jointing compound.

2.4. Formwork

Formwork kits are available to assist with construction.

These can be purchased from:
David Lawry, SPACE Down Under,

Mobile: 0418 806 803,

PO Box 206, Highgate, SA 5063

A video showing the installation method is available at:
https://youtu.be/Tgd0hJKLabc

Figure 10 - Formwork for a TreeNet Installation

2.5. TreeNet Construction Inspections

The contractor shall provide the superintendent/superintendent's representative with the opportunity to inspect works at each site at the following stages:

- Setout
- Completion of pipe installation, prior to crushed rock placement
- Final completion

Contractor is to provide a minimum of 24 hours' notice of the required inspection times.

The contractor shall take photos at the completion of each stage. Photos shall be provided to the superintendent/superintendent's representative. During construction the superintendent/superintendent's representative may deem that photographic evidence is satisfactory for some hold points.

3. General Requirements

3.1. Underground Services

The contractor shall take all reasonable steps to confirm the location of all underground services prior to commencement. This includes lodging a Dial-Before-You-Dig enquiry, contacting asset owners, visual inspections, underground location scanning and potholing.

3.2. Demolition

Materials required to be demolished become the property of the contractor and are to be removed from the site and appropriately disposed. The contractor shall provide containers for the safe storage of all demolished materials.

3.3. Concrete

Concrete is to be 32MPa at 28 days, or better.

Lintel concrete shall be 50MPa or better at 28 days.

All finished concrete surfaces are to be non-slip.

Concrete colour is to best match existing concrete kerbing.

3.4. Damage to Existing Assets

The contractor is responsible for repair of any existing assets damaged during the works.

3.5. Site Restoration

Disturbed areas are to be graded to be free draining and are to match existing adjacent areas forming a neat and regular finished profile. All disturbed areas are to be topsoiled, seeded and watered.

3.6. Subsidence

The contractor is responsible for regular monitoring of the site for subsidence for 12 months after installation, and shall promptly place additional topsoil as needed to address any subsidence issues.

3.7. Traffic and Pedestrian Management

The contractor must safely manage vehicle and pedestrian traffic for the duration of the works in accordance with current standards and practice, and relevant legislative, authority and asset owner requirements.

Prior to commencement a pedestrian and traffic management plan for the works must be developed satisfaction of the asset owner and relevant authorities.

A certified traffic controller must be on site at all times during construction.

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ZERO ADDITIONAL MAINTENANCE WSUD SYSTEMS:
CLOGGING POTENTIAL OF ALTERNATIVE FILTER MEDIA ARRANGEMENTS

Belinda Hatt, Veljko Prodanovic & Ana Deletic

INTRODUCTION

Filter media have a key functional role in biofiltration systems, in that they support the overlying plant community and contribute to filtration of pollutants. They must therefore have an adequate infiltration capacity to ensure long-term system efficiency, and critical properties include structural stability, to withstand compaction under occasional loading (e.g. pedestrian traffic, lawn mowers), as well as the capacity to absorb incoming sediment that may otherwise develop a clogging layer.

The Urban Water Group in the Department of Civil Engineering at Monash University has undertaken extensive performance testing of stormwater filtration systems which has led to the development of a number of design recommendations (e.g. FAWB 2009b; FAWB 2009a) that are widely used by the urban water industry. In particular, they found that use of an entirely engineered sand filter media provides comparable pollutant removal performance to the loamy sand that is generally recommended, with the advantage that this material (triple-washed sand) is readily available (Bratieres *et al.* 2009). In a related study into the impacts of alternative filter media arrangements on the longevity of stormwater filters, Kandra et al. (2014)found that layering the filter media according to decreasing particle size delayed the onset of declining infiltration capacity caused by clogging.

The aim of this study was to test the clogging potential of alternative filter media arrangements in a biofiltration system vegetated with turf grass. It forms part of a larger study that is focusing on designing and prototyping a Zero Additional Maintenance WSUD Solution, led by Manningham City Council in partnership with Glen Eira City Council, Melbourne Water and the CRC for Water Sensitive Cities.

METHODS

The trial was conducted using laboratory-scale biofilters columns based on the approach successfully used by the Urban Water Group in related studies.

Column design

Vegetated biofilter columns were constructed from 100 mm PVC pipe, with a total filter depth of 400 mm and a 200 mm ponding zone (Figure 1). All columns contained a 300 mm treatment zone which overlay a 50mm deep sand transition layer and a 50mm gravel drainage layer (Table 1, Figure 1). Within the treatment zone, six alternative filter media arrangements were tested (Table 1). All columns were planted with lawn grass (Soft Leaf Buffalo). Prior to planting, the plant roots were washed to remove the soil in which the grass was grown, since this soil would have constrained the infiltration capacity of the system. It should be noted that, although it is proposed to incorporate a saturated zone in the field-scale prototypes, only the upper, unsaturated layers of filter media were constructed for this study since the focus was on physical clogging. In total, 18 columns (6 designs x 3 replicates) were constructed.

Table 1. Matrix of alternative column designs.

Configuration	Filter media		Vegetation
	Depth (mm)	**Details**	
1	300 50 50	'FAWB' engineered media Transition layer Drainage layer	lawn grass
2	50 50 200 50 50	2mm coarse sand 1mm coarse sand 'FAWB' engineered media Transition layer Drainage layer	lawn grass
3	100 200 50 50	50/50 mix of 2mm and 1mm coarse sand 'FAWB' engineered media Transition layer Drainage layer	lawn grass
4	100 200 50 50	50/50 mix of 1mm and 0.5mm coarse sand 'FAWB' engineered media Transition layer Drainage layer	lawn grass
5	100 200 50 50	Burdetts 20/30 Sand 'FAWB' engineered media Transition layer Drainage layer	lawn grass
6	100 200 50 50	Daisy's Coarse White Sand 'FAWB' engineered media Transition layer Drainage layer	lawn grass

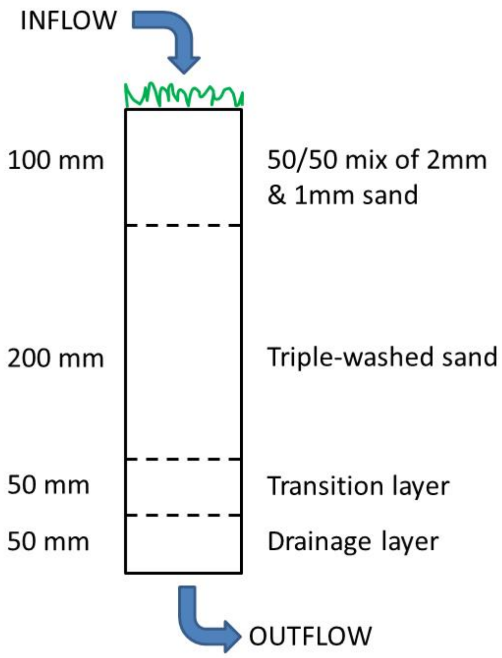

Figure 1. Illustration of the filter media arrangement in Configuration 3.

Establishment & stormwater dosing protocol

The biofilter columns were allowed to stabilise for one week following construction. During this time, they were irrigated periodically with tap water. Following this establishment period, the columns were dosed with semi-synthetic stormwater using an accelerated dosing approach. Semi-synthetic stormwater was prepared by mixing a slurry of sediment collected from the sediment pond of a local constructed wetland with tap water in a tank to achieve a target sediment concentration of 150 mg/L (Duncan 2006).

The aim of the stormwater dosing regime was to load the biofilter columns with the equivalent of 18 months of inflow over 15 days. To achieve this, the biofilter columns needed to be dosed with 16 L of stormwater per day (2L was added at hourly intervals eight times per day). The volumetric inflow equivalency was calculated using typical biofilter design (2% of the catchment area , FAWB 2009a) and rainfall characteristics for Melbourne (effective annual rainfall = 550 mm, BOM 2009).

Flow and sediment monitoring

To assess the development of clogging, outflow rates were manually measured three times a day. Inflow samples were also collected on a daily basis and analysed using a standard method (APHA/AWWA/WPCF 1998) to check the inflow sediment concentration.

RESULTS & DISCUSSION

The change in outflow rate across the dosing period is shown in Figure 2. It can be seen that, in all cases, there is a rapid initial decline in outflow rate followed by a slow decline up to the end of the dosing period. This rapid decline is typically observed during the establishment period of filters, even though the filter media was compacted during construction, because particles rearrange and settle as water flows through the media profile. It should be noted that there are differences in cumulative inflow volumes because, as the columns began to clog, some did not fully drain between dosing intervals. When this occurred, the hourly dosing volume was the volume of water that filled the ponding space.

There is generally very close agreement between replicates. Although there is greater variation between replicates for Configurations 2 and 5 than would be considered ideal (Figure 2), this is still not entirely unsurprising due to the heterogeneity of the filter media and the inherent level of uncertainty associated with the flow measurements.

The mean outflow rates after the initial decline are presented in Table 2. These outflow rates were calculated from a cumulative outflow volume of approximately 90L onwards (the point at which the initial decline had ceased in all columns). All designs containing a protective layer delayed the onset of clogging compared to the design with no protective layer. However, taking into account the variation in flow rates, both within and between design replicates, there is no real difference between any of the designs that contain a protective layer.

Table 2. Mean outflow rates after the initial decline (post-90L) for six design configurations (standard deviation shown in parentheses).

Configuration	Protective Layer	Outflow (mm/h)
1	None	75 (28)
2	2 + 1 mm sand (separate layers)	133 (37)
3	2 + 1 mm sand (mixed layer)	107 (34)
4	1 + 0.5 mm sand (mixed layer)	126 (45)
5	Burdetts 20/30 Sand	166 (38)
6	Daisy's Coarse White Sand	101 (30)

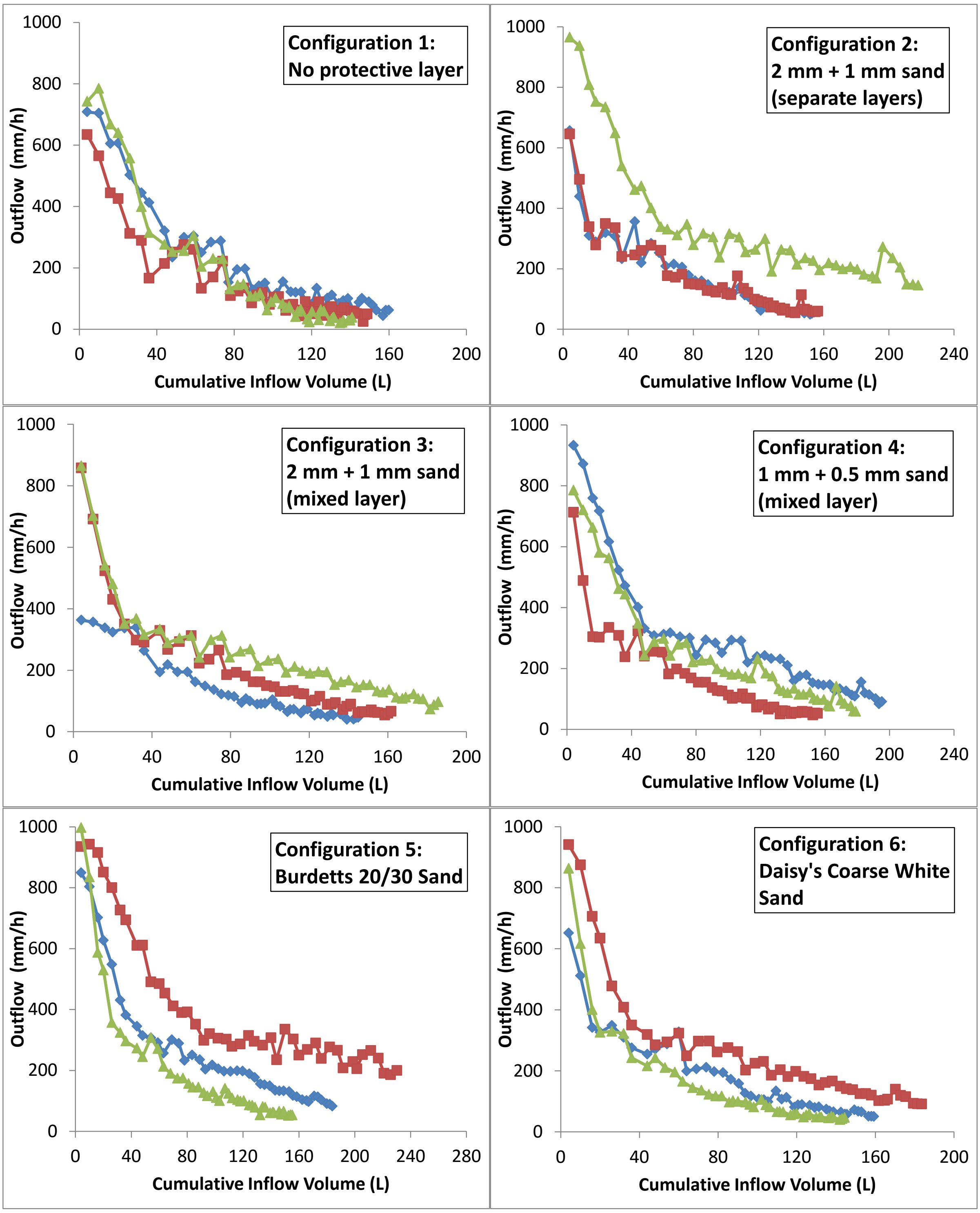

Figure 2. Change in outflow rate against cumulative inflow for six filter media configurations. Results for individual replicates are shown for each configuration.

The selection of the protective layer configuration needs to consider complexity of construction, cost, and capacity to support healthy plant growth as well as ability to delay the onset of clogging. Since there is no real difference in the performance of the five different protective layers, the choice is determined by the remaining considerations. A single layer protective system is far more practical to build than a mixed layer system. The cost of the commercially-available Burdetts and Daisy's sand products is approximately 20% of the engineered sands. Finally, the use of a coarser material for the top 100-150 mm of the media profile is unlikely to impact plant growth as even the root systems of shallow-rooted plants, such as lawn grasses, penetrate well beyond this depth. In a laboratory study of plant species in biofiltration systems, it was found that 95% of the root system of Soft Leaf Buffalo occupied the entire unsaturated zone (300 mm deep) and that some roots were sufficiently long to penetrate well into the saturated zone (>300 mm deep, Payne 2013). In light of these considerations, it is recommended that either the Burdetts 20/30 Sand or Daisy's Coarse White Sand be used as the protective layer.

CONCLUSIONS

An accelerated-dosing column study was conducted to assess the ability of six alternative filter media arrangements to delay the onset of clogging in laboratory scale biofilter columns. It was found that all designs that contained a protective surface layer were able to maintain a higher infiltration capacity compared to the design that did not contain a protective layer. However, there were no real differences in the performance of the five protective layer designs. In light of this result, and practical considerations such as cost, complexity of construction and the ability to support healthy plant growth, it is recommended that either Burdetts 20/30 Sand or Daisy's Coarse White Sand be used as the protective layer.

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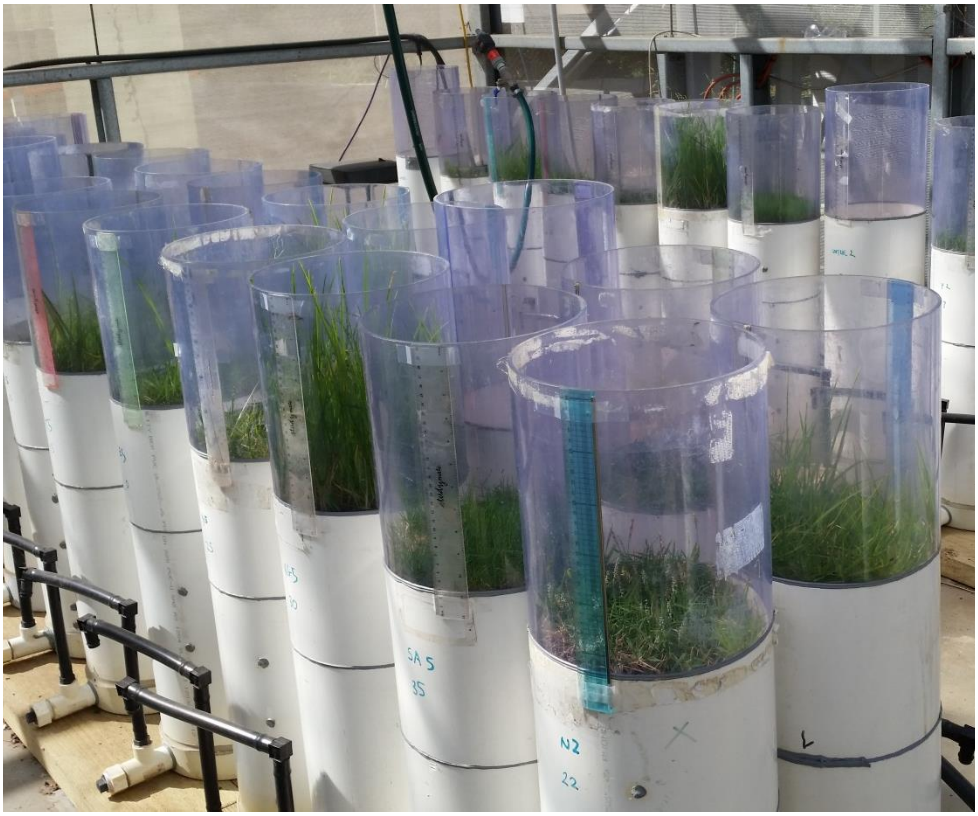
The performance of turf grass species in ZAM-WSUD stormwater biofilters



Final report

April 2018

Manningham City Council

Monash University

Prepared by

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MONASH University Engineering

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Executive summary

Manningham City Council, in partnership with Melbourne Water and the CRC for Water Sensitive Cities, has been testing novel stormwater biofiltration systems that aim to require no more than typical council maintenance works (i.e. 'Zero Additional Maintenance' WSUD systems). Planting with lawn grasses comprise one such design modification of these ZAM-WSUD systems. A trial of five different lawn grass species, tested for their survival and growth in the field, found that different site conditions require different lawn grass species to best suit the environment. While the field trial only assessed grass survivability, the nutrient removal abilities of various lawn grasses remain unknown. The aim of this project was to quantify the nutrient removal performance of a range of lawn species and elucidate on their capacity to meet regulatory requirements and best practice standards.

A 6-month laboratory column trial was set-up in an open-air greenhouse at Monash University where six different lawn grasses were dosed with semi-synthetic stormwater at different intervals, hence simulating wet and dry weather conditions. A total of four water quality sampling campaigns were conducted during which time inflow and outflow water samples were collected for analysis of their nitrogen and phosphorus concentrations (two sampling events). Infiltration rate measurements were also periodically conducted to assess whether any species were associated with fast- or slow-drainage. In response to the results of this initial laboratory trial, the experiment was extended for another five months to incorporate an additional set of testing under wet and dry weather respectively.

The results found that the grass species (including Kenda Kikuyu, Village Green Kikuyu, Santa Ana Couch, Empire Zoysia and Palmetto Soft Leaf Buffalo) are likely able to meet best practice stormwater management standards in terms of pollutant reduction. Nitrogen removal performance was relatively poorer for some species during winter, during which time the grasses went into a period of dormancy, indicating a seasonal variation in removal performance. After establishment, all species performed comparatively well under both wet and dry weather conditions.

In summary, the results of this trial indicate that various lawn grasses can be effective for nitrogen removal as long as they grow well and are healthy. The key message is, essentially, that for a particular site, choose the lawn species that is more likely to thrive under that particular site condition and this will most likely translate into effective nitrogen treatment performance (slower growing plants will have lower percentage reductions). In this study, Kenda and Village Green Kikuyu were the best performers, followed by Santa Ana Couch, Empire Zoysia, Palmetto Soft leaf Buffalo and Nara Native Zoysia) at start-up (winter and spring). During summer when the species were relatively mature, all species were identical in their nitrogen removal performance.

Table of Contents

1. Introduction

Manningham City Council, in partnership with Melbourne Water and the CRC for Water Sensitive Cities, has been testing novel stormwater biofiltration systems that aim to require no more than typical council maintenance works (i.e. 'Zero Additional Maintenance' WSUD systems). This was driven by an increasing need for WSUD across the urban environment, but the limited capacity to fund maintenance of a growing asset base into the future. The program has successfully installed, trialled and refined various ZAM-WSUD designs at multiple sites and has led to the generation of a freely available ZAM-WSUD handbook to facilitate widespread adoption of these low maintenance systems (the ZAM-WSUD handbook is available through the Clearwater website at https://www.clearwater.asn.au/news/zero-additional-maintenance-zam-wsud-at-manningham-city-council.php). Following to the success of the research project, Manningham Council is considering opportunities to integrate ZAM-WSUD into Council's Capital Works Program, as a regular component of projects.

Initial field trials were largely planted with Palmetto Soft Leaf Buffalo, as the performance of this lawn species for nutrient removal from stormwater was tested by Monash University in biofilter column tests (Payne et al., 2014a). In this laboratory-scale study (using small columns of 150 mm diameter) buffalo grass was associated with good removal of both nitrogen and phosphorus. However at some field sites with high sun exposure the Palmetto Soft Leaf Buffalo was not surviving well, particularly during establishment and this led to testing of a wider range of lawn grass species.

A field trial of five different lawn grass species were tested for their survival and growth at a site with high pedestrian traffic (adjacent to a car park) and high sun exposure. The results showed that different site conditions will require different lawn grass species to best suit the environment, including degree of sun/shade exposure, pedestrian traffic and proximity to environments sensitive to invasion. For instance, after four months of growth (across autumn and winter) Kenda Kikuyu and Empire Zoysia grew particularly well. Palmetto Buffalo was doing relatively well, followed by Nara Native Zoysia with fair to good survival.

The field trial only assessed grass survivability, and the nutrient removal capabilities of these various lawn species remains unknown. The potential for species to differ significantly in their nutrient removal capabilities, most critically for nitrogen, has been demonstrated in multiple studies (Read et al., 2008, Bratières et al., 2008, Payne et al., 2014a). Multiple councils are interested in the use of grassed biofiltration systems but without understanding how different turf varieties differ in their performance. There is uncertainty surrounding their capacity to meet regulatory requirements and best practice standards.

This document reports on a six-month laboratory study undertaken by Monash University in collaboration with Manningham City Council. The objective of this study was to test a range of lawn grasses for their nitrogen and phosphorus removal ability. Performance during dry periods has also been tested. As clogging has been problematic for some lawn grasses previously tested (particularly Velvetene (Pham et al., 2012)), infiltration rates were also measured during the lab study. This document, ultimately, attempts to make recommendations regarding the most effective lawn grass species for installation in ZAM-WSUD systems.

2. Methodology

2.1 Lawn grass species tested

Palmetto soft leaf buffalo, Kenda Kikuyu, Empire Zoysia, and Nara Native Zoysia have been trialled in the field. Field trials of the Palmetto SS100 cultivars showed that they can be grown in biofilter sands, for “full sun” sites with dry soils. The trials indicated that for south eastern Australian climatic conditions, sterile male Kikuyu species Kenda and Village Green) are most suitable for sites with minimal shade (<20%). Empire Zoysia was found to be more suitable for low to medium pesdestrian traffic sites with part shade (20-40%). Santa Ana Couch may also be generally suitable, but has not yet been trialled in field installations. The following six lawn species (Figure 1) were, thus, tested for their nutrient removal ability to assess their suitability for use in ZAM-WSUD applications.

Figure 1 Lawn grasses tested in the laboratory trial

2.2 Experimental set-up

35 columns were set-up (including five replicates of each lawn species and five non-vegetated controls) in an open-air greenhouse with a clear impermeable roof. The columns were constructed from 240 mm diameter PVC pipe, with a transparent Perspex top section allowing for plant growth and ponding of water (Figure 2). The insides of the columns were sand-blasted to reduce preferential flow along the column edges. Columns were filled with different layers of media as shown in Figure 2. Freshly sourced lawn grasses were laid into a total of 30 columns. The remaining 5 columns were left un-vegetated, thereby acting as controls and to inform on the performance of bare sites with poor grass survival. Depth of the saturated zone was 300 mm (by raising the outlet pipe); this comprised the gravel and transition layer.

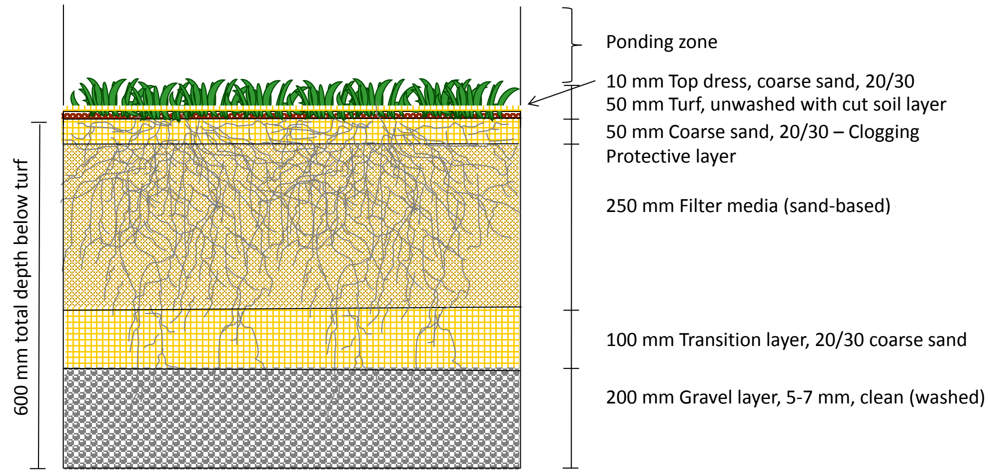

Figure 2 Schematic of biofilter cross-sectional profile

2.3 Experimental procedure

2.3.1 Plant establishment

A liquid fertiliser (Multicrop Plant Starter Liquid Fertiliser) was added after planting (~2L after dilution with tap water). Plant establishment period lasted for six weeks during which time the grasses were watered with approximately 2 L of tap water three times per week for the first two weeks to ensure survivability. The watering frequency was then reduced to twice per week. Lawn grasses were mowed as necessary during the trial period.

2.3.2 Semi-synthetic stormwater dosing and water quality sampling

In early June 2017, dosing of the columns with 9.4 L of semi-synthetic stormwater twice weekly commenced. This dosing regime was based on an annual average effective rainfall of 540 mm/year for Melbourne and using a biofilter sized to 2.5% of its contributing catchment. Use of semi-synthetic stormwater allowed us to minimise variations in inflow concentration whilst maintaining realistic composition. It contained sediment from a local stormwater retention wetland, sieved to 1 mm and mixed with dechlorinated tap water to achieve the target TSS concentration. Laboratory chemicals (potassium nitrate, ammonium chloride, nicotinic acid, potassium sulphate and sodium thiosulphate) were added to match any deficit in targeted pollutant concentrations as detailed in Bratieres et al., 2008. Target nutrient concentrations were shown below.

Pollutant	Target concentration (mg/L)
Total nitrogen, TN	2.10
Total phosphorus, TP	0.35
Total dissolved nitrogen, TDN	1.60
Ammonia, NH_3	0.27
Oxidised nitrogen – sum of nitrate and nitrite, NO_x	0.75
Particulate organic nitrogen, PON	0.50
Dissolved organic nitrogen, DON	0.59

Over the 6-months study period, both wet and dry weather conditions were simulated; 5-months of wet period (twice weekly dosing) and 1 month of dry period (dosing once per fortnight) were simulated (Figure 3).

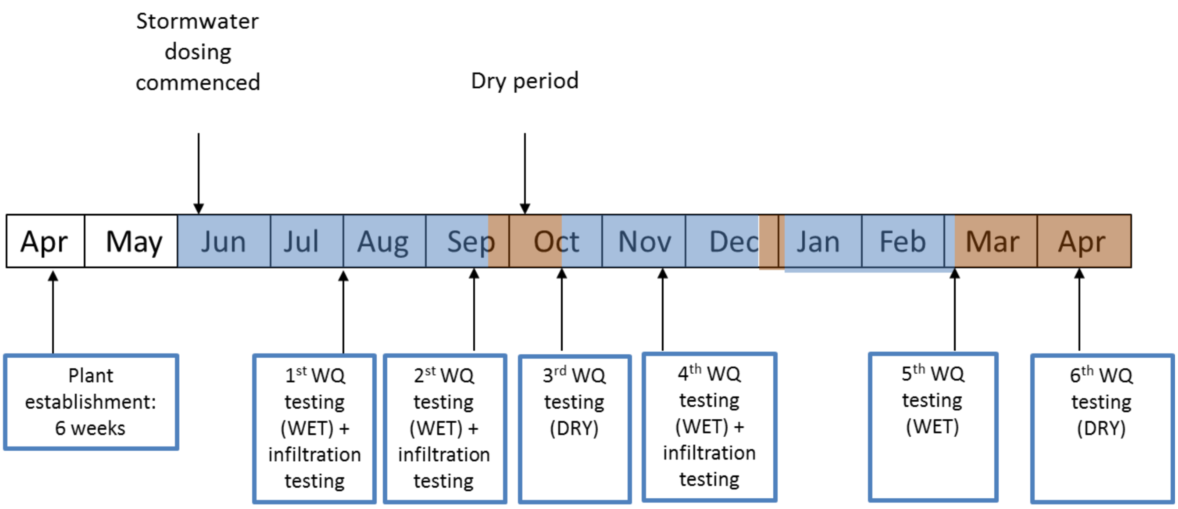

Figure 3 Dosing and sampling schedule (April 2017 to April 2018)

A total of four sampling runs were conducted over a period of 6 months. During each sampling run, inflow and outflow water samples were collected. A composite outflow sample was taken after the column finished draining. This was sub-sampled into a 1 L bottle. All samples were analysed in a NATA (National Association of Testing Authorities, Australia) accredited laboratory according to standard methods (Hosomi & Sudo, 1986; APHA/AWWA/WPCF, 1998). All sampling runs were analysed for TN, TDN, NH_3, NO_x while the last 2 sampling runs were also analysed for TP, TDP and FRP (filterable reactive phosphorus, a measure of orthophosphate, PO_4^{3-}). DON was calculated as the difference between TDN and NH_3 + NO_x. The difference between TP and TDP is a measure of particulate phosphorus.

Trial extension for monitoring nitrogen removal

Initial results found species-specific difference in the grasses growth rate which, in turn, influenced their nitrogen removal rate (see further Figure 6). To get a better idea of the removal performance over the long term as grasses become established, the trial was extended for a period of five months during which time, an additional two sampling runs were undertaken (Figure 3).

2.3.3 Infiltration rate measurements

In order to ensure that the grass species had an adequate drainage rate over time and were not subject to clogging, infiltration rate measurements were conducted at regular intervals (Figure 3). During a dosing event, the drop in ponding water level was measured every 60 s for at least 15 minutes depending on the rate of drainage of the column. The infiltration rate was calculated as the average decrease in water level over measurement time.

3. Results and discussion

3.1 Infiltration rate

Three infiltration rate measurements were conducted over the 6-month study period to determine any clogging behaviour and identify any species associated with slow or fast drainage. After 15 weeks since planting (August, after about 8 weeks of stormwater dosing), the average infiltration rate amounted to 456 mm/h and there was no significant difference across grass type. Rates slightly increased in September 2017 (i.e. after about 14 weeks of stormwater dosing) and significantly increased from September 2017 to November 2017 for all grass species (Figure 4). This increase could be due to weather conditions (that is lower rates during winter vs spring) as well as the development of grass roots in the soil over time. In contrast, a decrease in infiltration rate was observed for the non-vegetated columns over time. This could stem from an accumulation of sediments on the surface of the filter media over time. The above results confirm the positive effect that vegetation has in WSUD systems in alleviating issues associated with clogging.

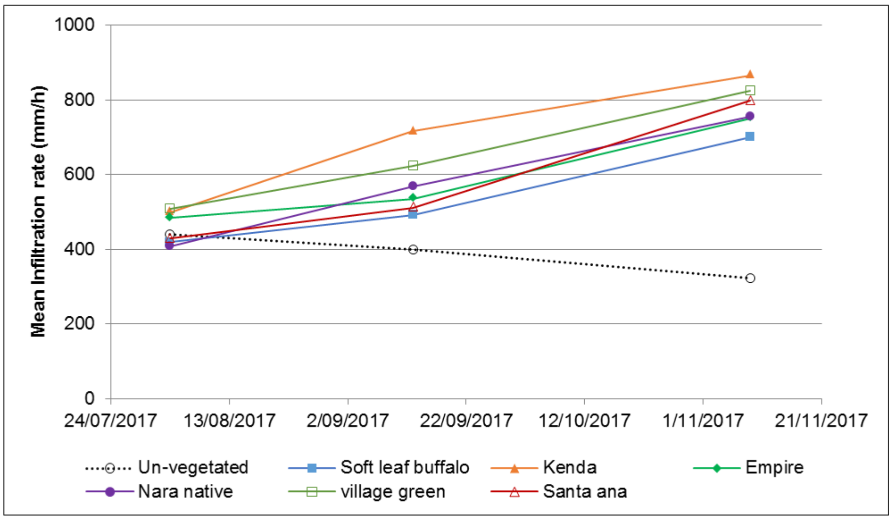

Figure 4 Evolution of mean infiltration rate over time for the different grass species

It should be noted the high infiltration rate measured in this trial (Figure 4) may not be reflective of field conditions (i.e. it is expected that infiltration rate would be lower in the field as a result of compaction due to vehicular and/or human traffic, litter accumulation, etc). Yet, these results give a clear comparison of the behaviour of different lawn grasses in the field.

Average infiltration rates were statistically similar across grass species ($p>0.05$) after 15, 21 and 28 weeks of planting respectively. Interestingly, particularly in November, planted columns had significantly higher infiltration rates than unplanted columns (Figure 5). Vegetation indeed loosens up the inside of the filter media with roots. Santa Ana Couch and Kenda Kikuyu had the least variation in infiltration rates across replicates whilst Empire Zoysia the greatest (Figure 5).

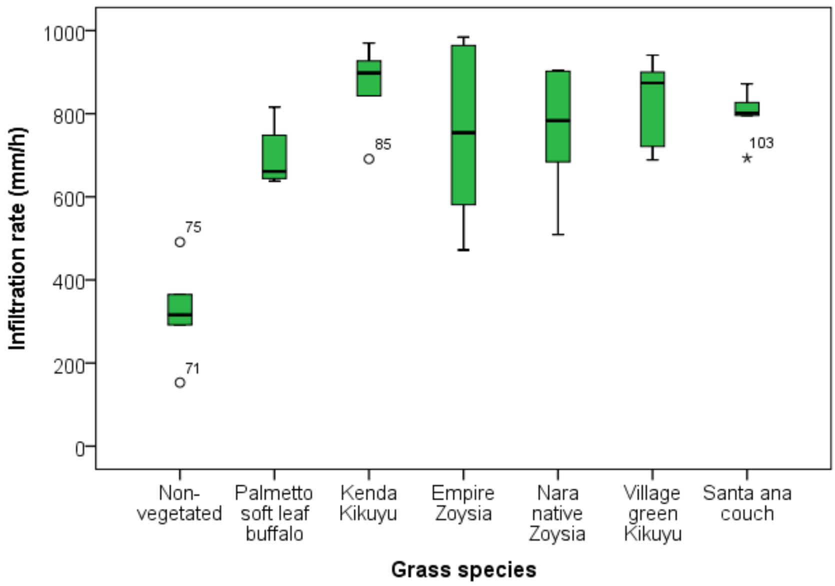

Figure 5 Variation of infiltration rate across grass species after 6 months of stormwater inflow (November 2017)

3.2 Water quality

3.2.1 Nitrogen

The TN removal efficiency (calculated as a percentage of the difference in inflow and outflow concentration) and the variation of outflow NO_x, NH_3 and DON concentrations over time are shown in Figure 6 and 7 respectively. We can see a net removal of total nitrogen for all grass species in every sampling event, except for the non-vegetated and Nara native columns in the 3rd sampling (at week 26 where outflow concentrations were greater than inflow concentrations). Week 26 sampling occurred after 4 weeks of dry period (i.e. columns received stormwater only twice over a 30 day period). Reduced performance is typical after dry weather spells due to some root die-off and leaching from filter media and reduction in microbial activity as a result of desiccation. It is highly likely that Nara Native Zoysia had not well established at that time (it essentially went into a state of dormancy during winter) which resulted in a decrease in its performance. Indeed, as the lawn grasses matured and under summer conditions, all species experienced an increase in nitrogen removal. Interestingly, two weeks dry period had no significant effect on nitrogen removal during this period (see results at week 45 and 51, Figure 6).In general, columns planted with the grass species performed better than the bare columns. This is more apparent at week 45 and 51 which represent more mature conditions.

Removal was low in the initial sampling rounds because as mentioned previously the grasses were still establishing and the winter season caused some species to enter dormancy (particularly, Nara Native, Santa Ana, Palmetto Buffalo, Empire Zoysia). But at the end of spring (week 30), an increase in removal for most grass species was accompanied by an increase in grass growth to peak to approximately 80% removal at week 45 and 51. See also Figure 8 for visual images of the grasses in September vs November.

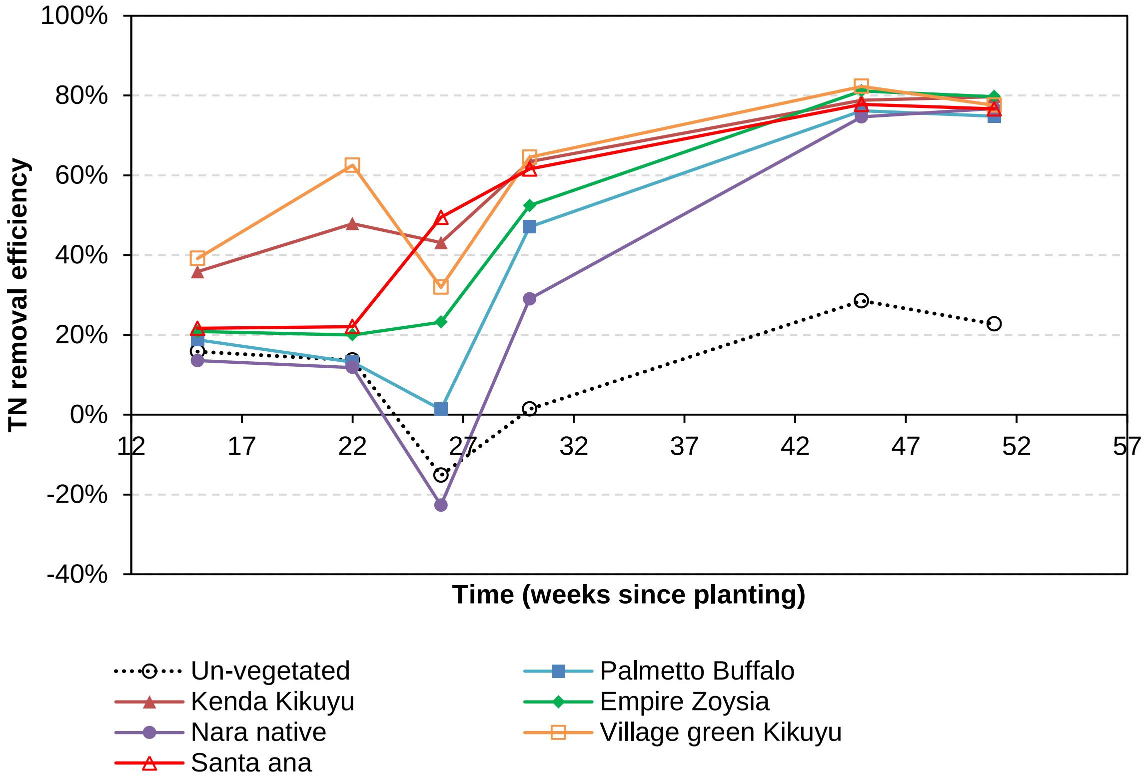

Figure 6 Average total nitrogen (TN) removal efficiencies over time for different lawn grasses

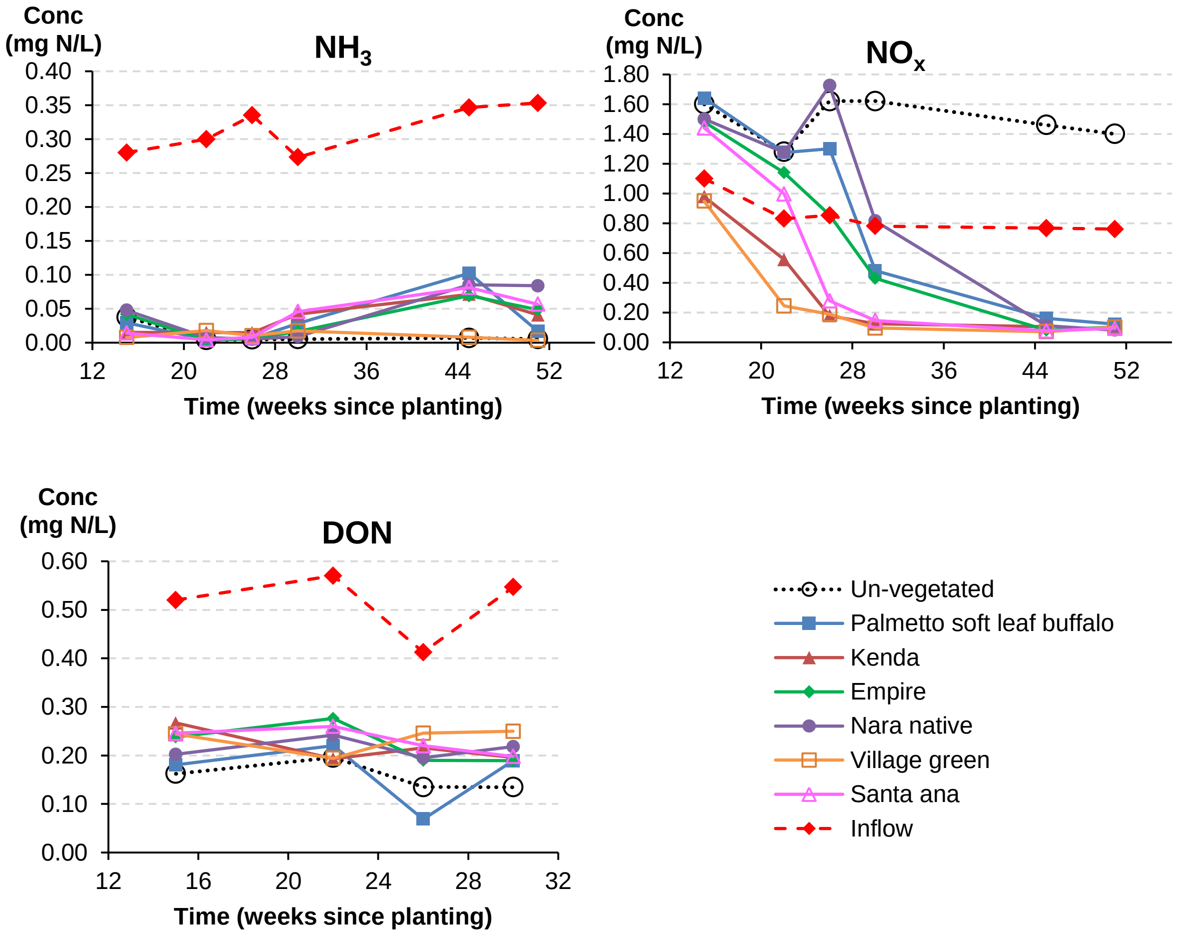

Figure 7 Effluent concentrations in column outflow of dissolved nitrogen species (ammonia, NH_3; oxidised nitrogen, NO_x and dissolved organic nitrogen, DON) across lawn grasses

Effluent NH_3 concentrations were low in all cases (Figure 7). NH_3 is mainly removed through adsorption and microbial processing via nitrification which occurred effectively. There was a net reduction in DON concentrations which occurred up to a background concentration. On the other hand, effluent NO_x concentrations varied during the study period, with some net production from nitrification (the microbial conversion of NH_3 to NO_x) and insufficient plant uptake in certain instances. A general decrease in effluent NO_x concentration was, nevertheless, observed with time. In fact, TN removal was dictated by the extent of NO_x removal and/or production.

Variation across grass species

There was a significant difference in TN removal and effluent NO_x concentrations across grass type ($p<0.001$) in the initial 4 sampling runs, with some species performing better than others (Figure 6). This difference could be attributed to the growth pattern of the different lawn grasses. For instance, some species were dormant during winter while others experienced active growth (particularly, the Kikuyu species), leading to higher removal performance. Previous studies have found that plant uptake likely plays a key role in nitrogen removal (Payne et al., 2014b). In the same vein, growth rate of the lawn grasses is likely another factor influencing nitrogen removal. Nara native Zoysia is known to be slow growing which explains its lower performance. Nara Native Zoysia also goes dormant during drought, which explains the poor performance during week 26.

Interestingly, after establishment and under more mature state, the difference in performance across lawn grasses became insignificant.

The results indicate that the lawn grasses are able to achieve a high removal efficiency which could meet best practice guidelines for stormwater management recommending at least 45% reduction in the field. Further field tests need to be conducted to confirm this.

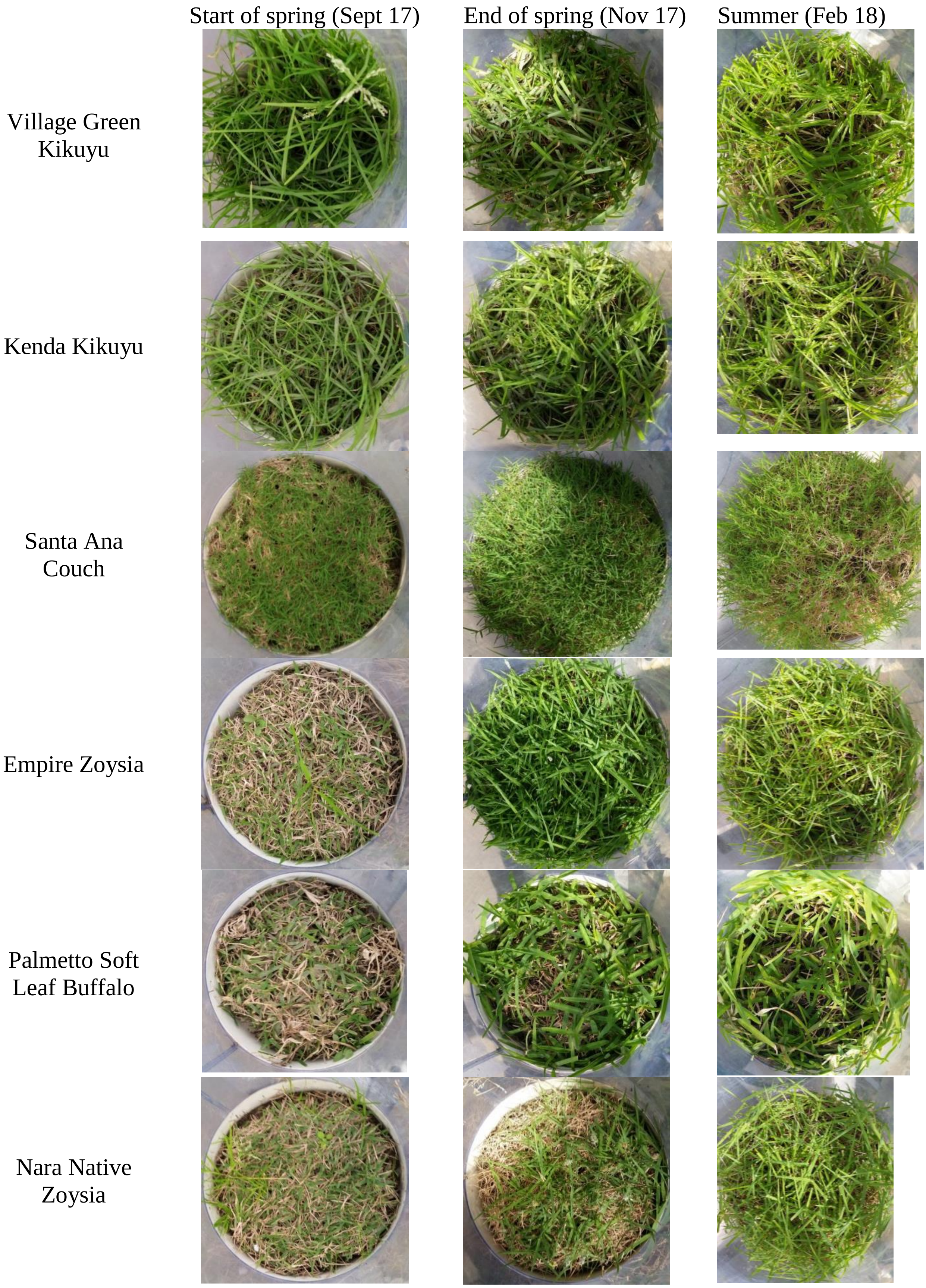

Figure 8 Comparison of the physical appearance of lawn grasses in August (Melbourne winter) and November (Melbourne spring end). Almost all lawn species showed good growth and greening in November.

3.2.2 Phosphorus

Phosphorus from stormwater is usually well-removed in biofilters since it is mostly associated with sediments and thus removed through physical processes. To verify the performance of TP in systems planted with lawn grasses, TP was analysed for only two sampling events: during October (dry period) and November (wet period). The results are presented in Figure 9. During the dry period (week 26), TP reduction ranged from -13% (Nara Native) to 26% (bare column). FRP removal ranged from 54% (Nara Native) to 91% (Kenda). Since FRP was mostly well-removed and most of the TDP was in the form of FRP, this signifies that the poor TP performance was due to leaching in the form of particulate phosphorus (see also Figure 10), released from the filter media and mostly from plant matter as a result of dessication as explained previously. During the wet period (week 30), a major improvement in phosphorus reduction was recorded with TP ranging from 14% (Nara Native) to 53% (bare column) while FRP ranged from 40% to 82%. Since most of the P in the effluent is bound to particles, that is, are potentially in a non-reactive/less bioavailable form, this minimises the environmental risk. In the future, a deeper transition layer comprising coarse sand can be implemented to screen fine particles migrating from the upper filter media. There was no significant difference in TP removal across grass species (p>0.05). Poorer removal of vegetated columns compared to non-vegetated columns could be leaching from plant matter.

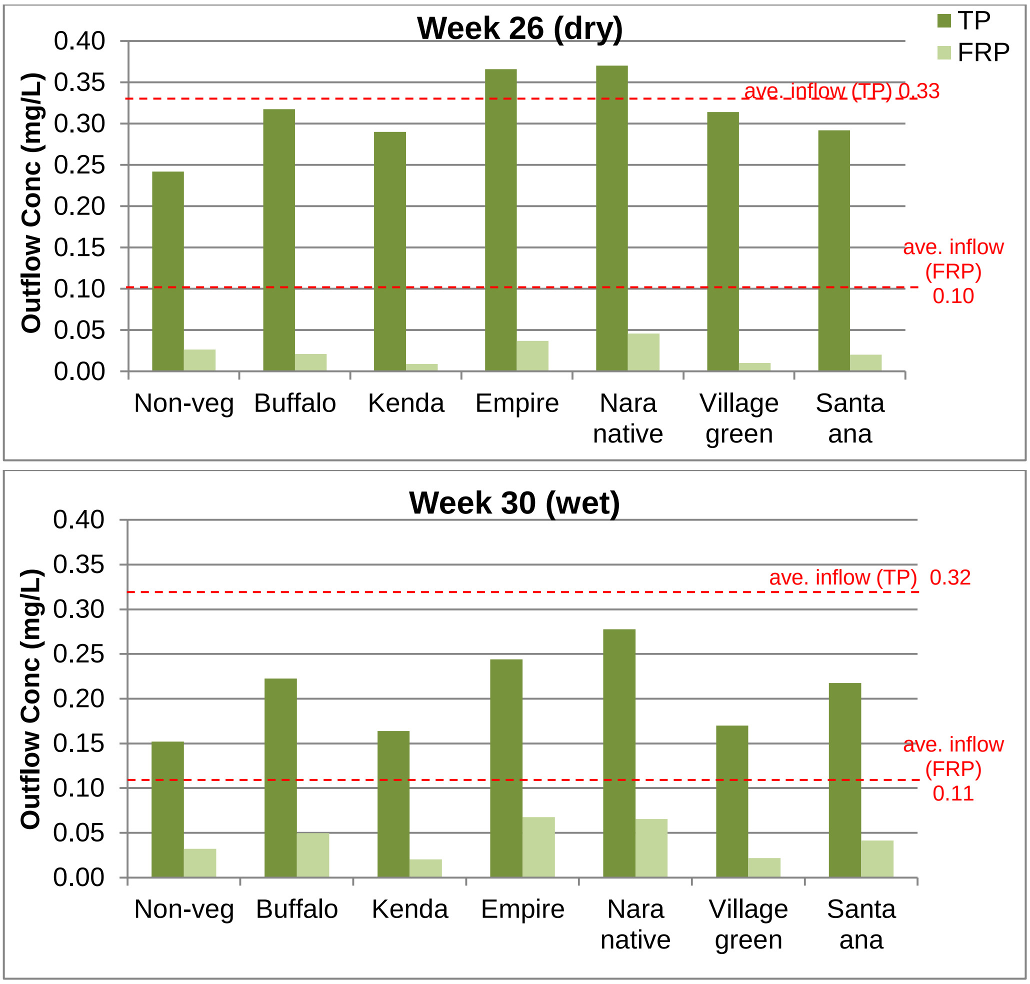

Figure 9 Comparison of average outflow total phosphorus (TP) and filterable reactive phosphorus (FRP, a measure of orthophosphate) concentrations across lawn grasses during dry and wet weather conditions

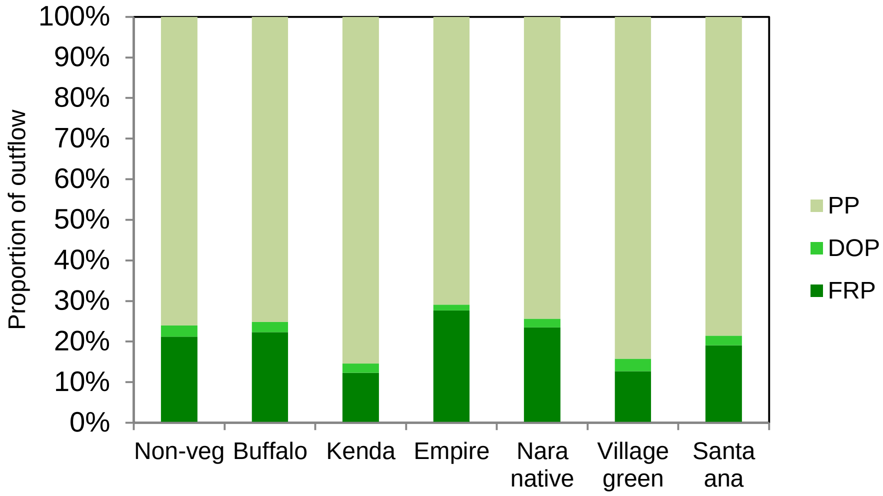

Figure 10 Proportion of outflow TP concentration as FRP, dissolved non-reactive P (DOP) and particulate P (PP)

4. Conclusions and Recommendations

The results of this study showed that biofilters planted with lawn grass species, including Kenda Kikuyu, Empire zoysia, Santa Ana Couch, Village green Kikuyu and Palmetto soft leaf Buffalo, could be effective for reducing nitrogen concentrations from stormwater. It was found that if installed under correct conditions, lawn grasses are able to meet regulatory requirements and best practice standards for nitrogen reduction (Victoria Stormwater Committee, 2006).

Because of their faster growth rate and probable growth during winter period, Kenda Kikuyu and Village Green Kikuyu were the best performing lawn species during the initial trial period.. At maturity, all species were universally effective at nitrogen removal.

Nitrogen removal may be poorer during the first few months as the grasses are establishing. It appears that lawn grasses may be more susceptible to seasonal variation in comparison with other species (e.g. native shrubs, sedge or ornamental plants) (Fowdar et al., 2017). For example, Nara Native Zoysia, Santa ana Couch and Empire Zoysia may go dormant during winter.

Clogging was not found to be an issue during the trial period.

While the effect of dry period could be more pronounced for some species during winter, all lawn species were able to maintain performance during summer in the present study.

The key message is that lawn species with poor survivability would result in poor nutrient removal. Lawn species that are healthy will provide the greatest benefit. Always choose lawn species that will grow well in the particular location (although slow growing species can be expected to render lower nutrient removal) for effective nutrient removal. For e.g., installing Kenda Kikuyu in a shady location (when it is not shade tolerant) will produce lower removal rates than Palmetto Soft Leaf Buffalo which is more shade tolerant.

From this study, while it can be speculated that nutrient removal of the lawn grasses is a function of grass health and growth rate, plant growth and vegetation mass changes were not monitored during this study. Further studies will validate this as well as whether nutrient removal is also based on other factors such as species type.

Table 1 Characteristics of lawn grasses and corresponding nitrogen removal performance

Lawn species	Characteristics	Nutrient removal performance (as per this study)
Village green Kikuyu	• High root volume for nutrient and water uptake. • Holds superior colour over the winter months compared to common Kikuyu • Maintains green colour and dense coverage for most of the year in Victoria • Drought tolerant • Winter active with an excellent recovery rate • Quick to establish a strong healthy root system	Effective
Kenda Kikuyu	• Fast establishment • Good drought tolerance • Good wear tolerance • Dense and deep root system • High winter activity	Effective
Santa Ana Couch	• Short dormancy period • Very deep root system • Recovers rapidly from damage • Goes dormant in winter	Effective (after establishment). Maintains performance during 15-weeks dry
Empire Zoysia	• Comparatively slower growth than Kikuyu or Couch • Drought tolerant • May be prone to brown off in winter • Slow to establish in winter • Winter dormancy	Effective after establishment
Nara native Zoysia	• Slower growing than Kikuyu and Buffalo • Faster growing than Empire Zoysia • Tends to produce a burst of seed head in early spring • Goes dormant in severe drought to survive • Some winter dormancy	Effective after establishment (not recommended in climates with frequent dry weather spells)
Palmetto Soft Leaf Buffalo	• Low maintenance (incl. watering) • Shade tolerant	Effective after establishment

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