Research behind Biofilter Adoption Guidelines v2

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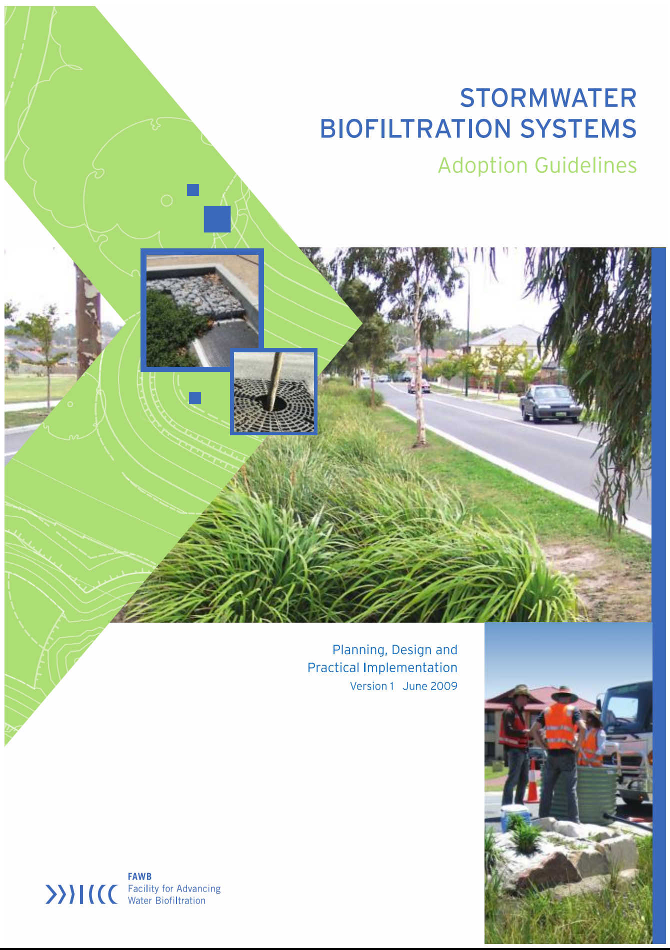
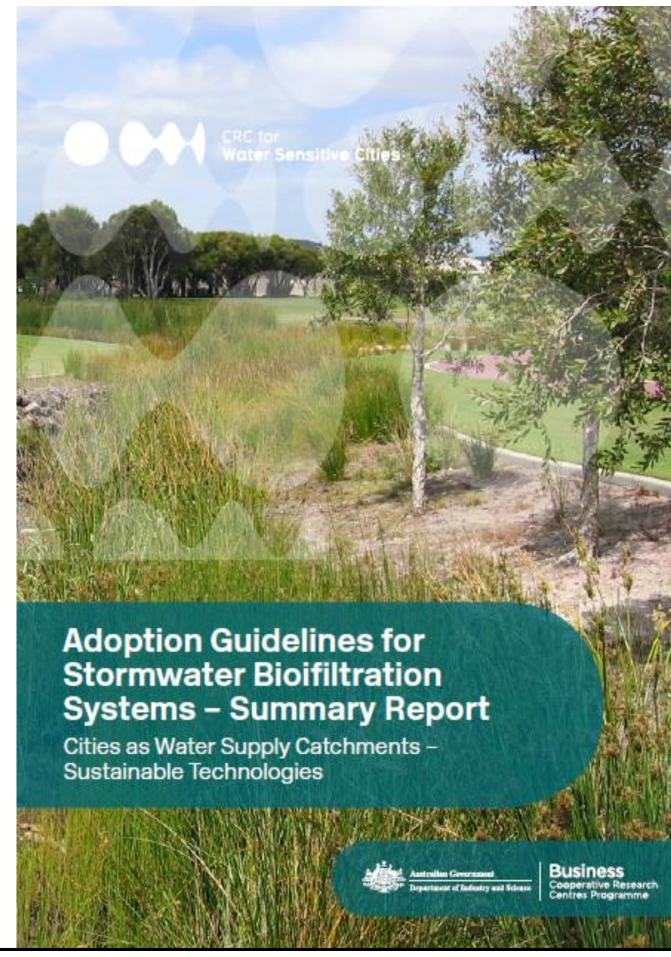
2009 → Research → 2015





Overview of recent research activities

1. CRCWSC Project C1.1 Sustainable Technologies (P1 of Cities as Water Supply Catchment)
2. ARC Linkage: The role of vegetation in nitrogen removal in biofilters
3. Monash PhD projects:
   - The effect of competition between plants on nutrient removal performance
   - Optimisation of phosphorus removal in stormwater biofiltration systems
   - Clogging of stormwater filtration systems
4. Piloting stormwater biofilters in Israel
5. Associated CRCWSC projects:
   - Project A4.1 Cities as Water Supply Catchments – Society and Institutions
   - Project Project A1: Economic Modelling and Analysis

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CRC C1.1: Sustainable Technologies

The aim was to develop novel and refine existing stormwater harvesting technologies, building upon the proven concepts of Water Sensitive Urban Design.

How to remove pathogens & micropollutants!

ARC Linkage: The role of vegetation in nitrogen removal in biofilters

- The aim was to further our understanding of the role of plants in biofilters.

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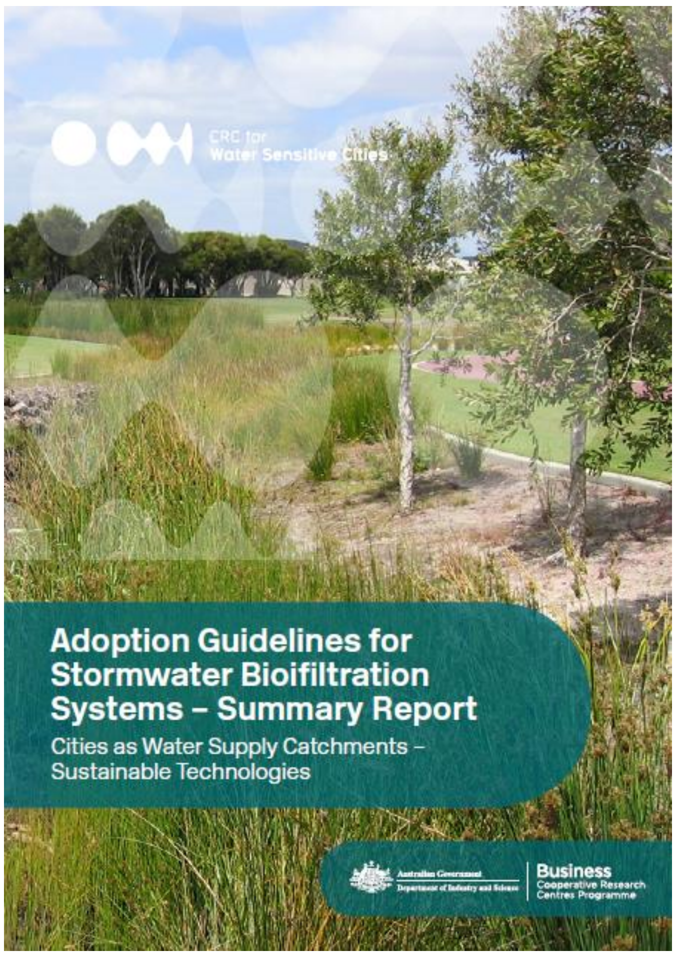

WHAT'S NEW IN VERSION 2 OF THE GUIDELINES?

- The business case for biofiltration
- Updated guidance on vegetation selection, media specifications and stormwater harvesting
- Updated design configuration guidance – inclusion of a raised outlet
- Guidance for landscape design and community acceptance – designing biofilters that look attractive
- Tips for designing systems for successful long-term operation, and low maintenance
- Tips to address challenging site conditions
- Illustrations and summaries of biofilter functions, key maintenance issues and important construction checks
- Summary of biofilter performance and key processes

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Business Case for Installing Biofilters

- They remove pollution and could treat water for outdoor irrigation
- They have small footprint
- They can be pretty
  - ✓ *The amenity value of streetscape raingardens in Sydney increased property values by around 6% ($54,000 AUD) for houses within 50 m and 4% ($36,000 AUD) up to 100 m away, while raingardens at a street intersection can generate around $1.5 million increase in residential value.*



Meredith Dobbie & Hamish Smilie

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How biofilters work

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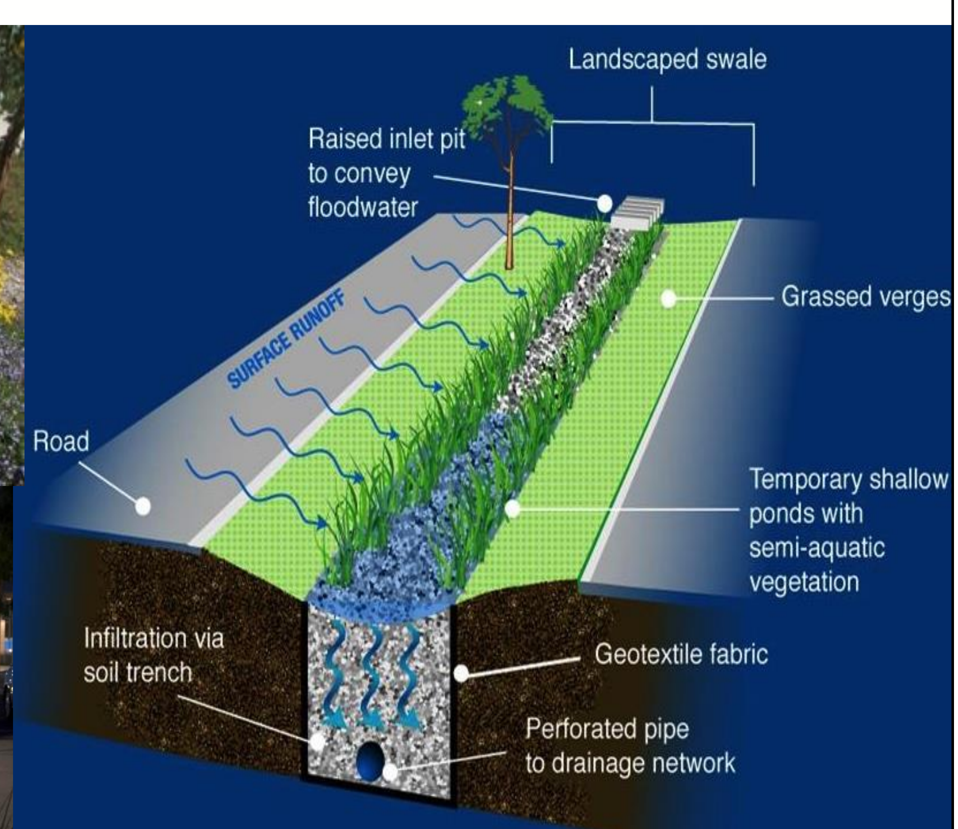
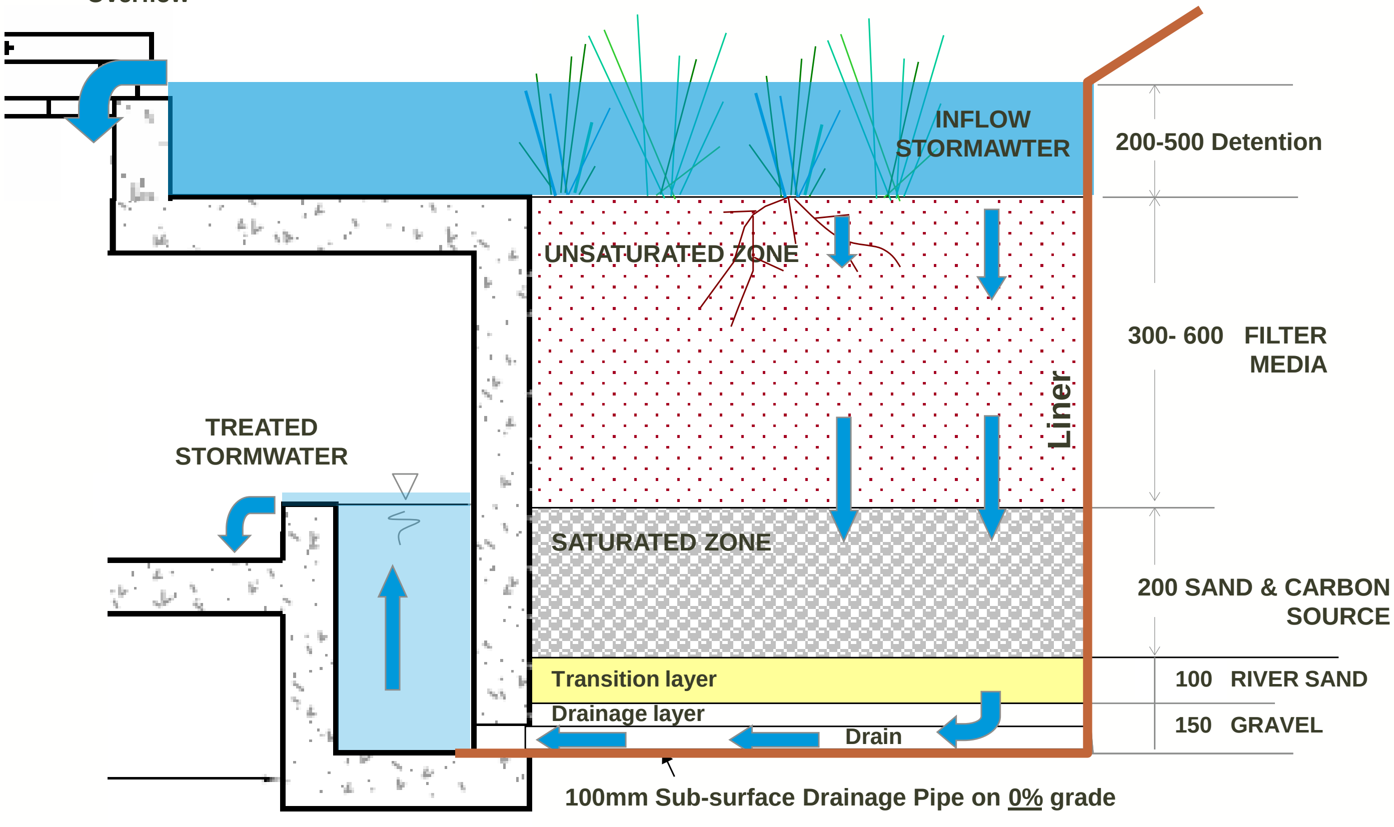
Stormwater Biofilters



How they work



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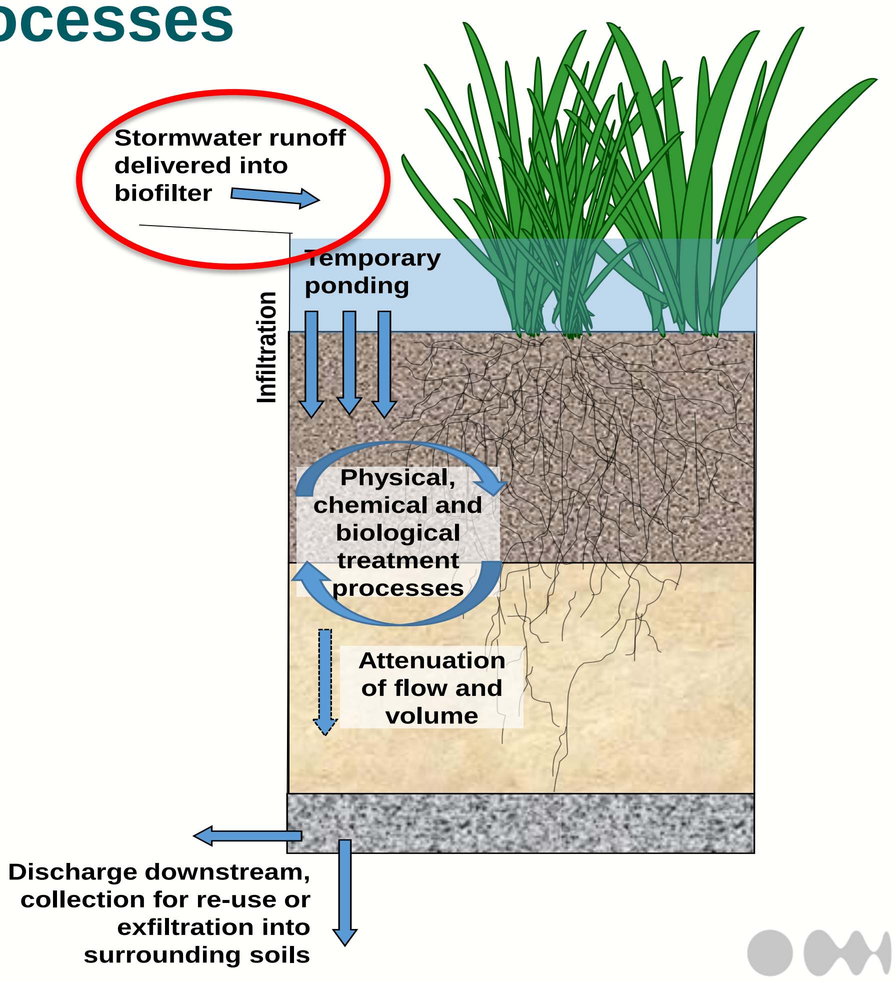
Key Processes



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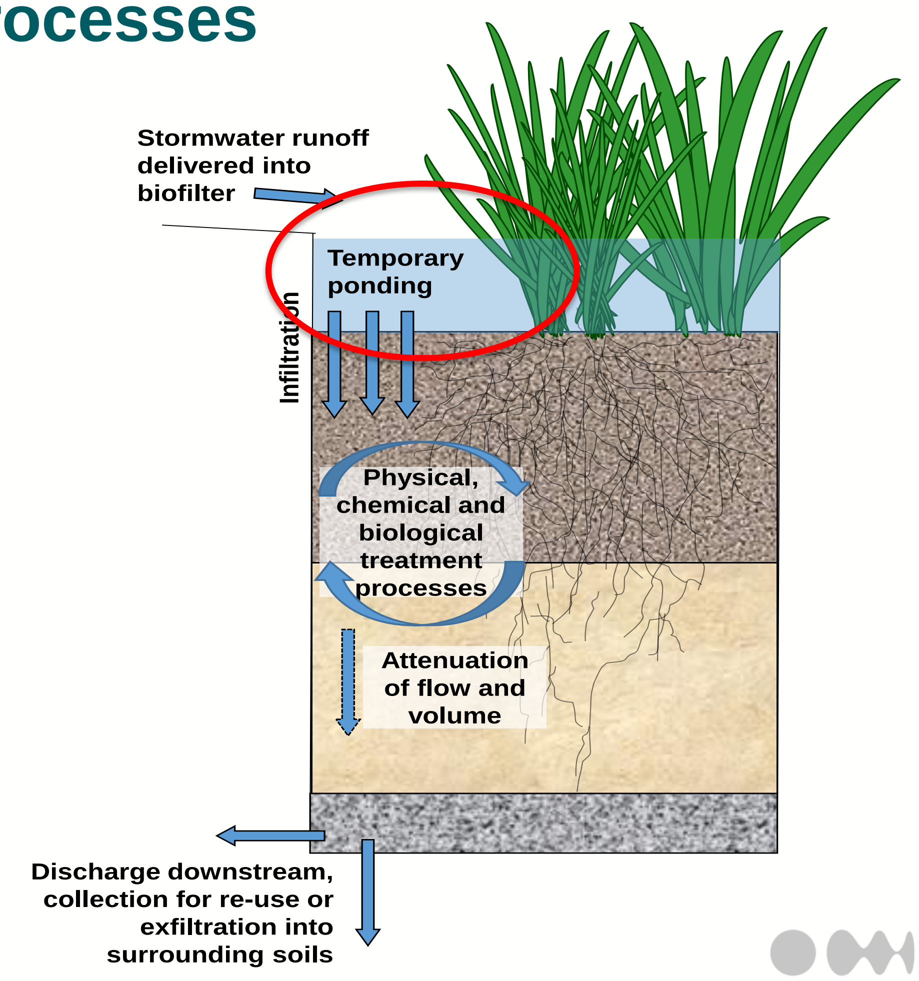
Key Processes



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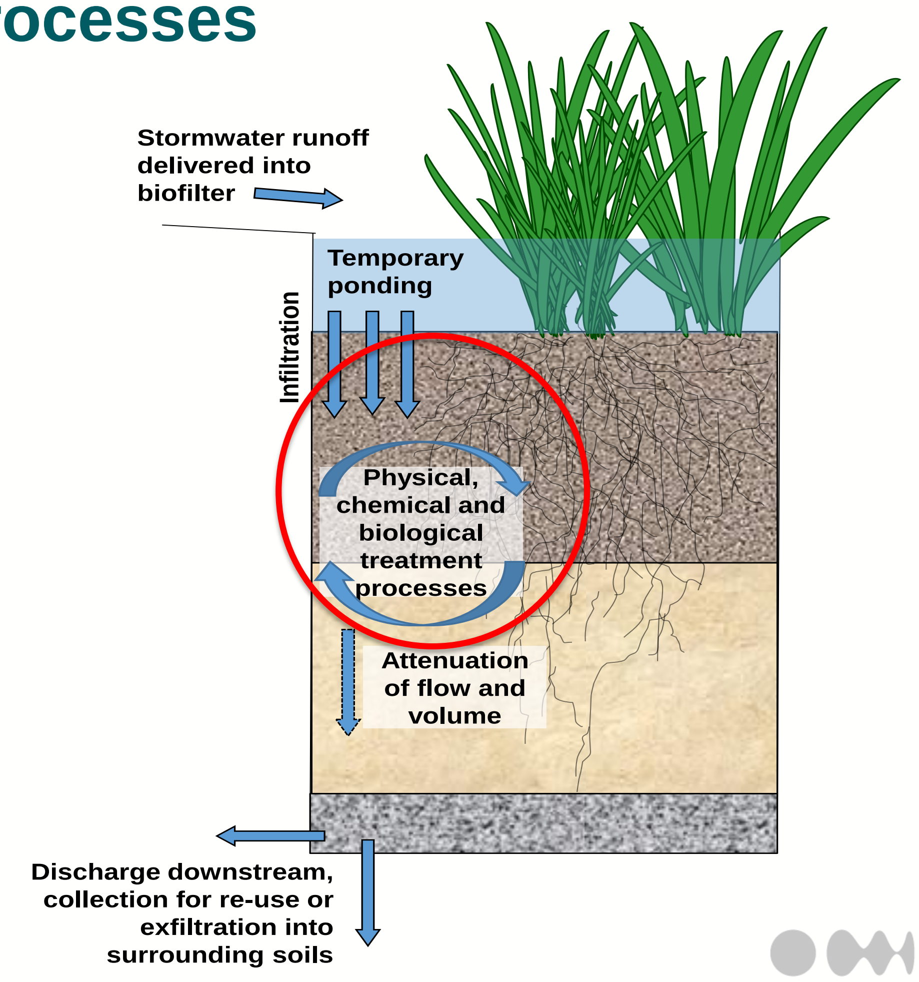
Key Processes



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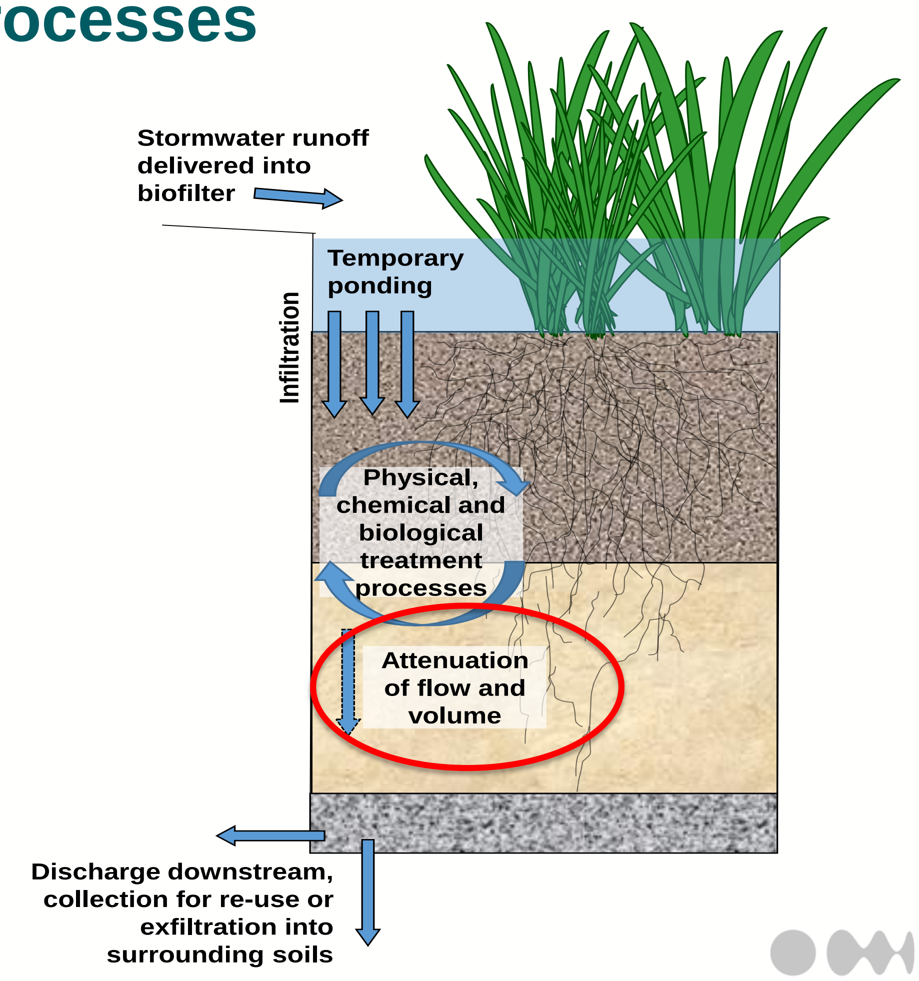
Key Processes



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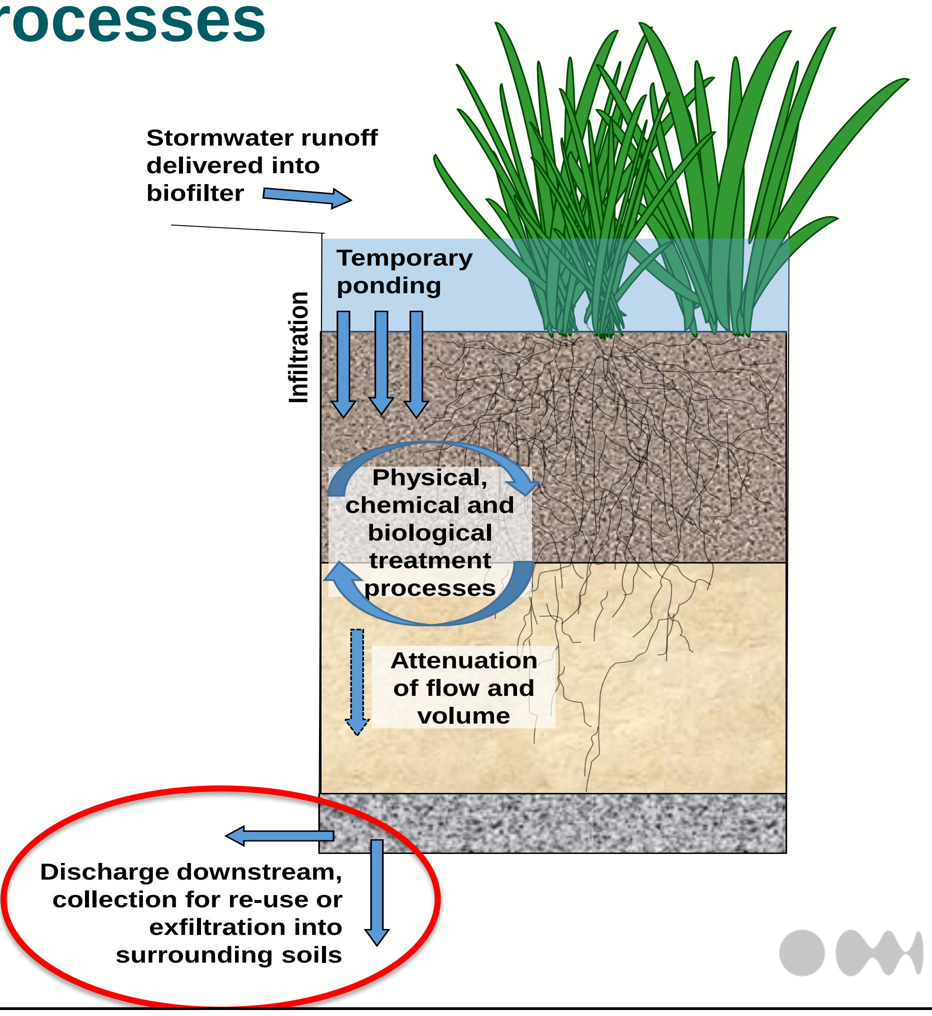
Key Processes



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The Key Components of Stormwater Biofilters

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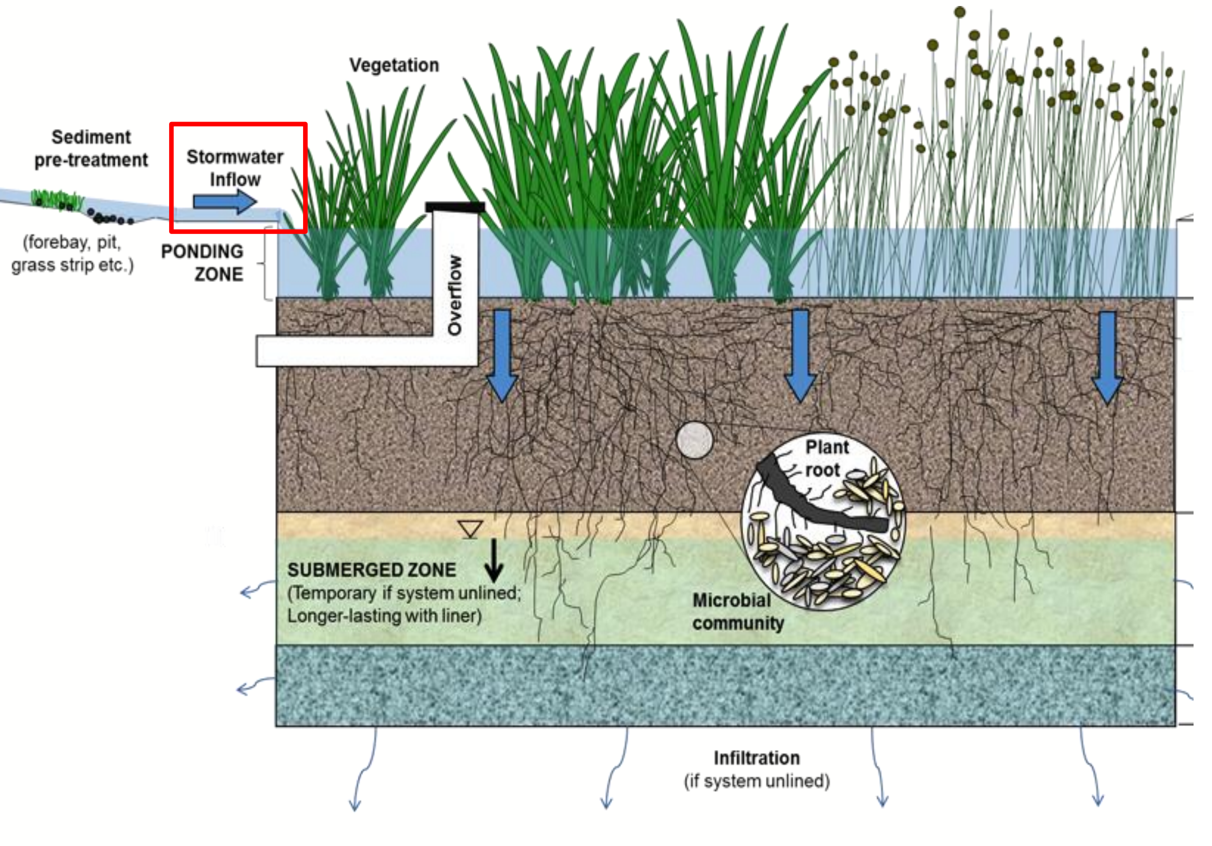
Essential Components



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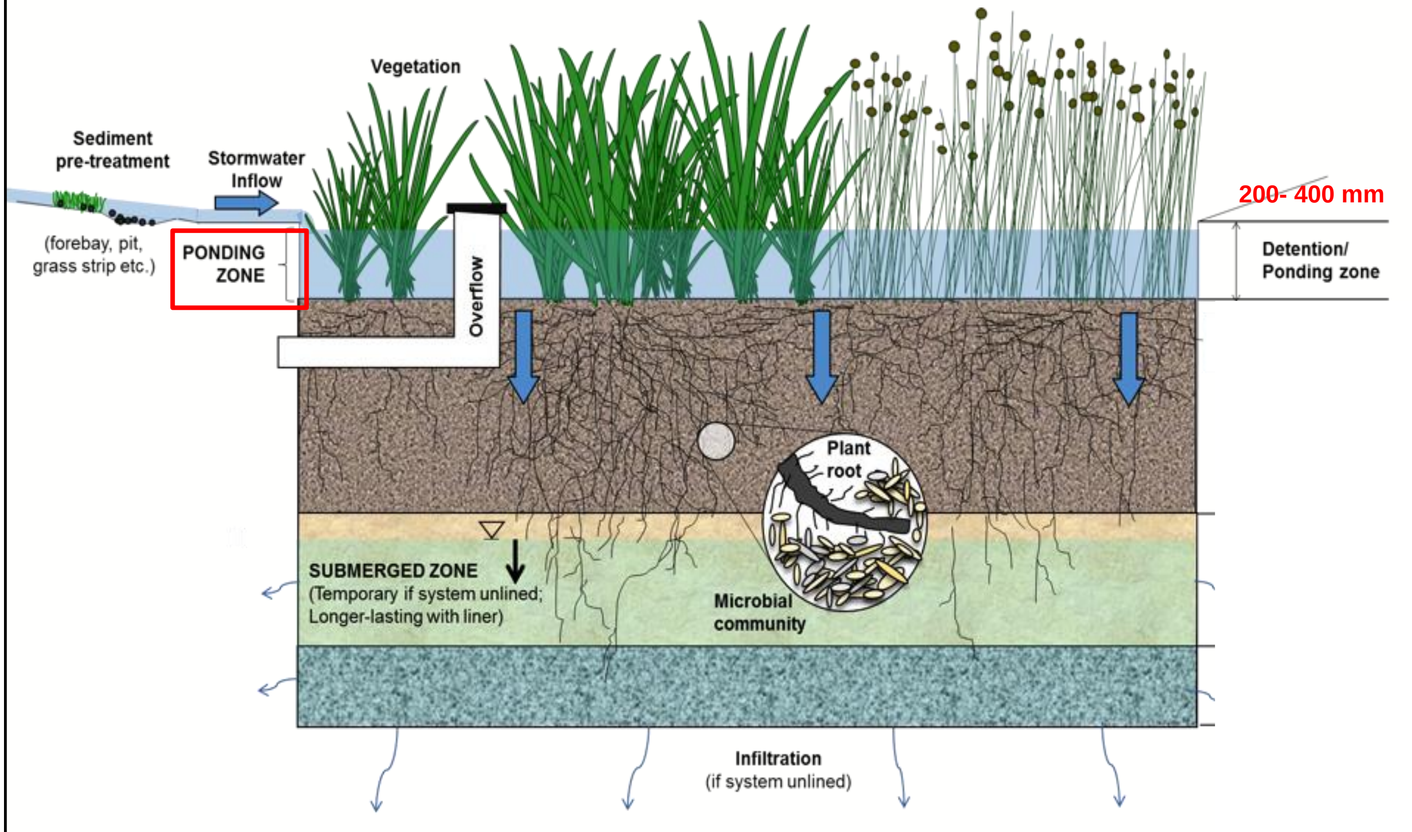

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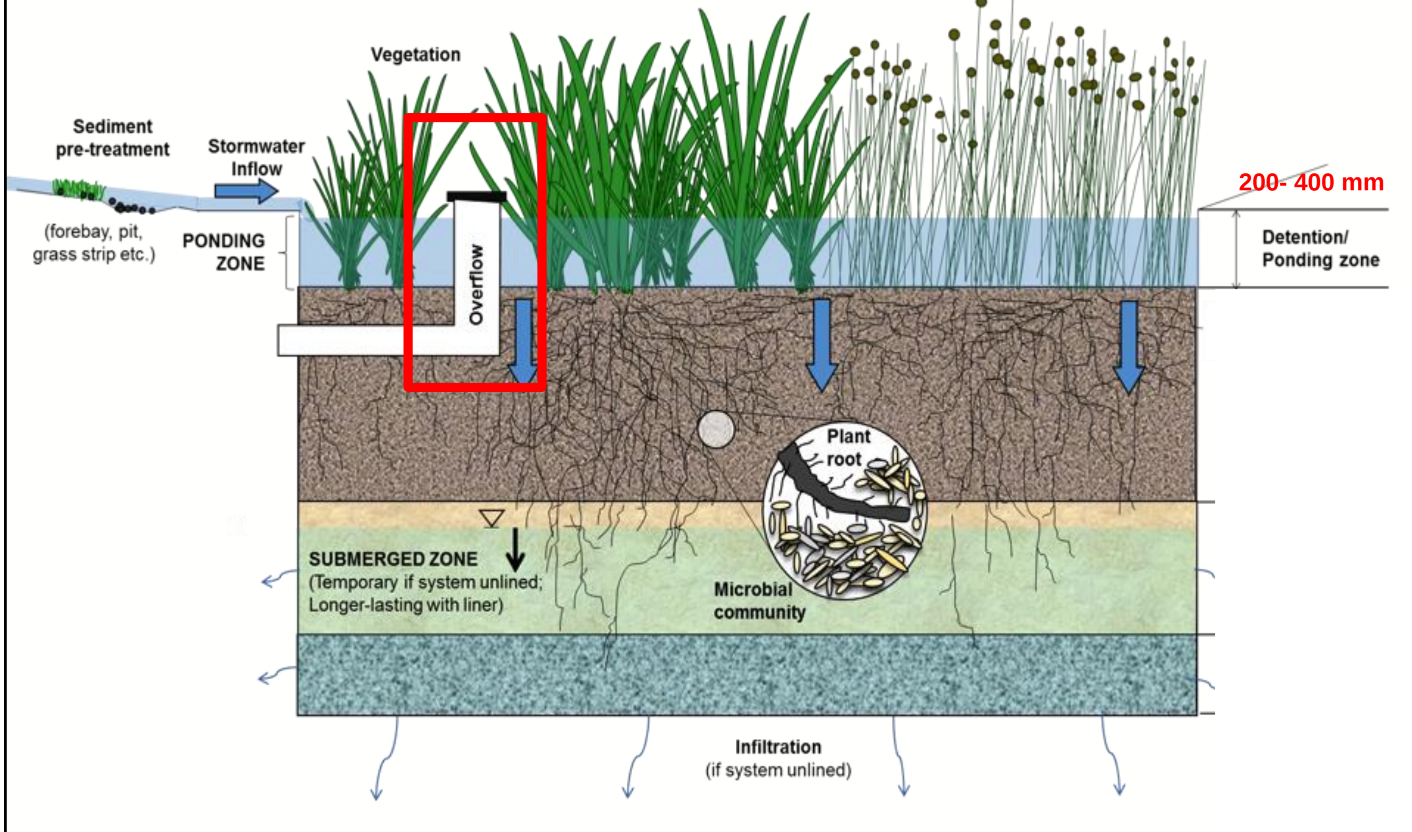

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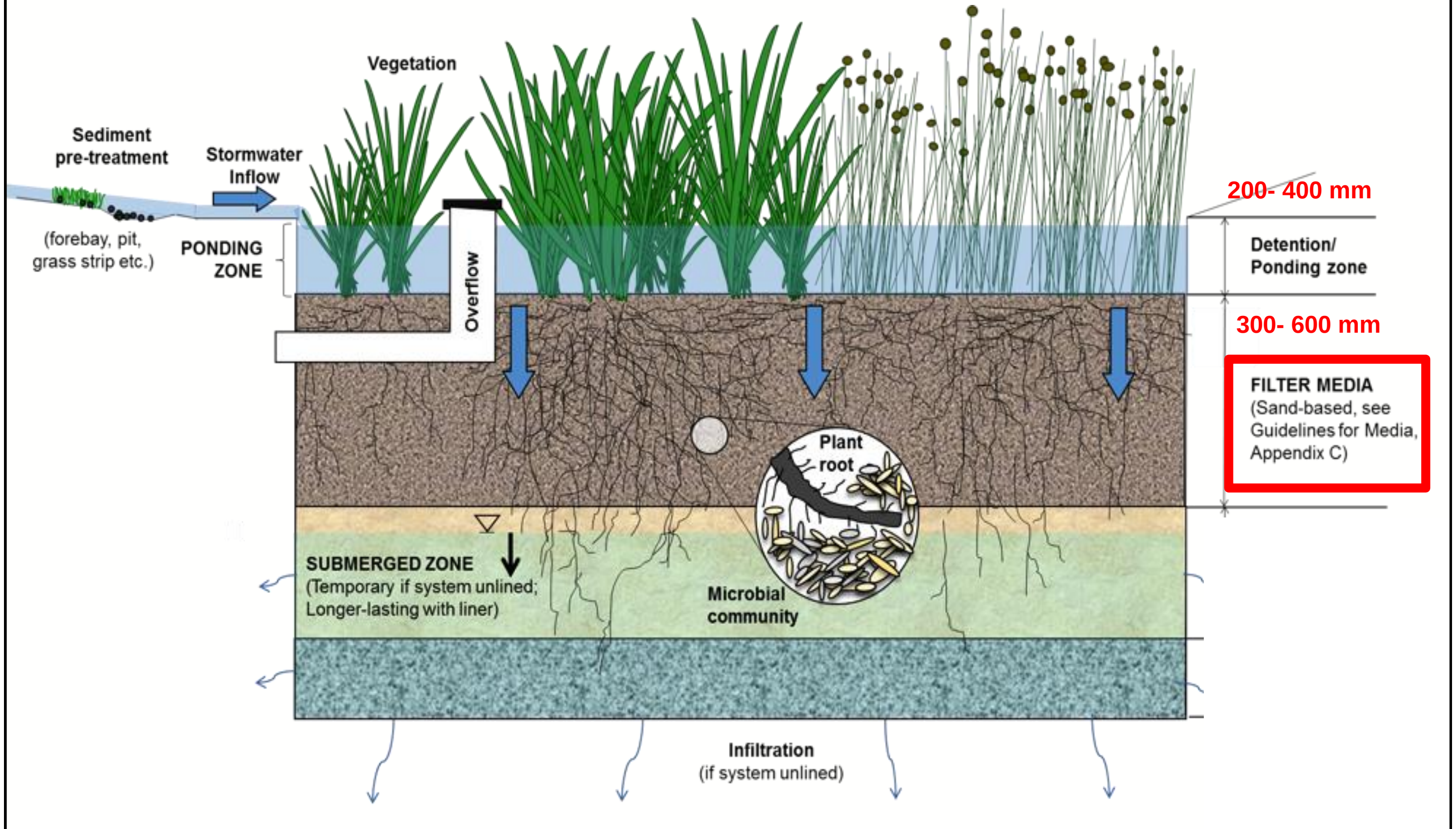

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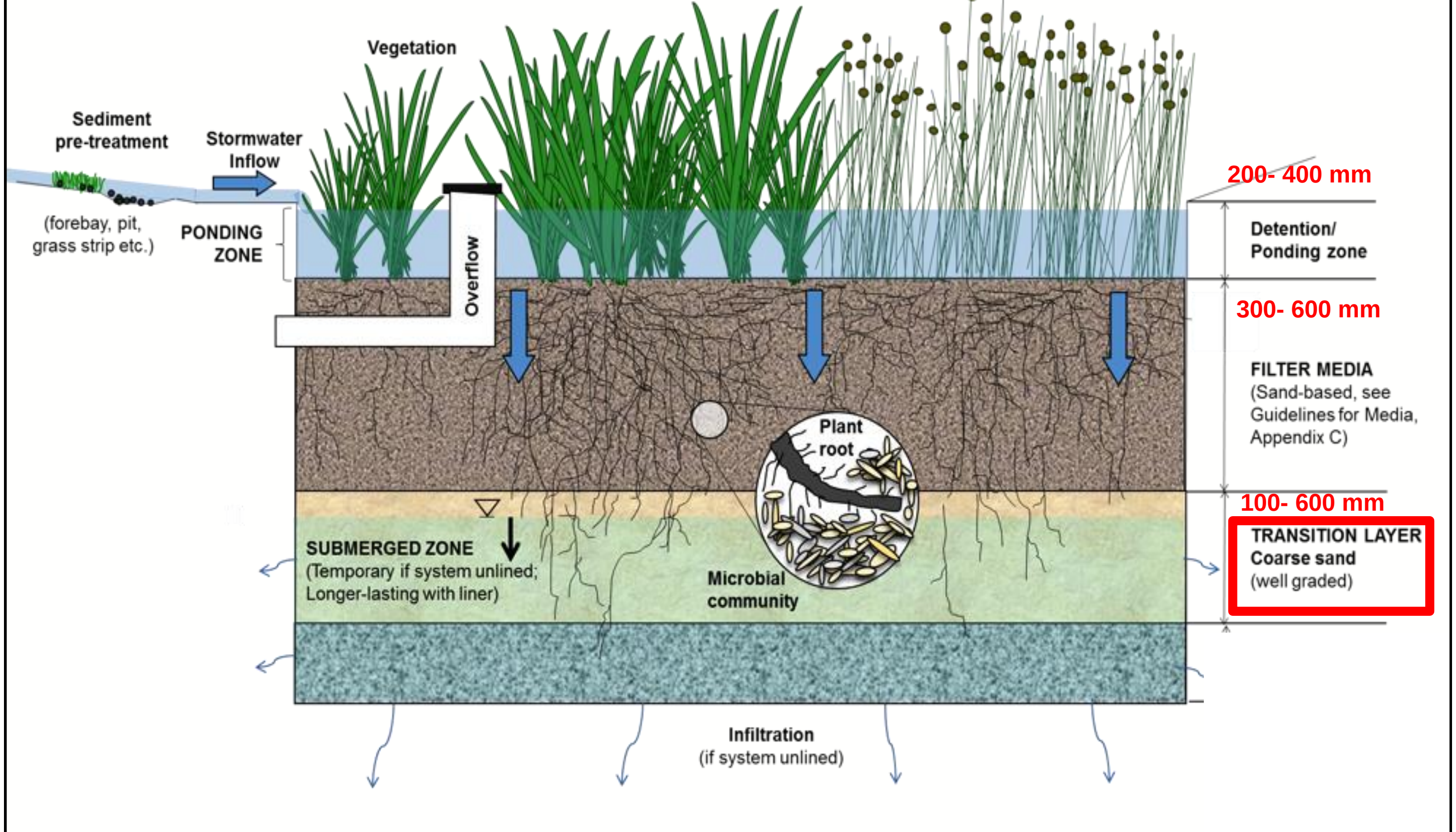
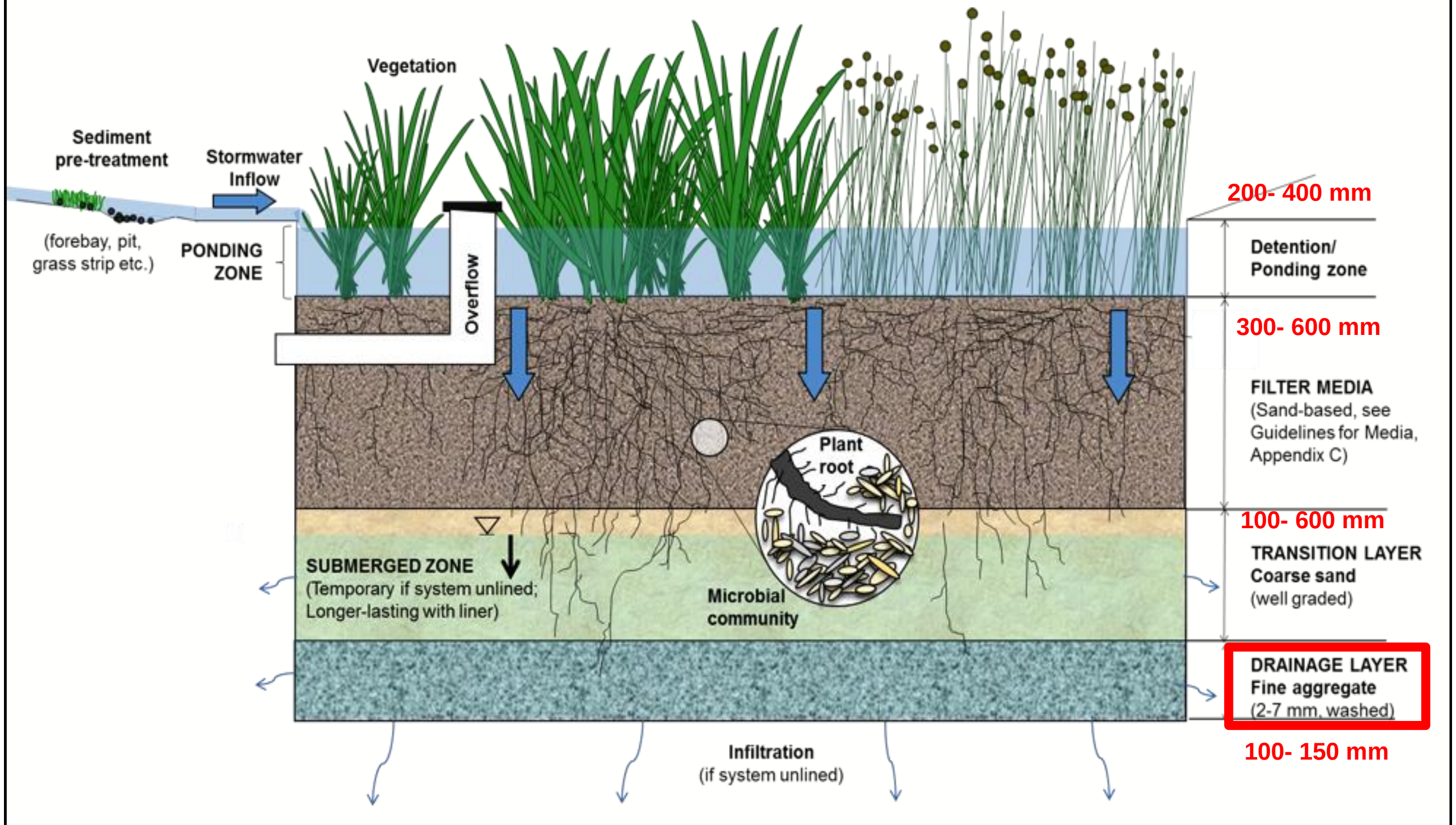


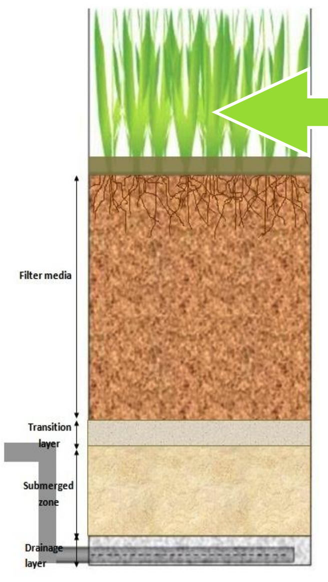
Essential Components



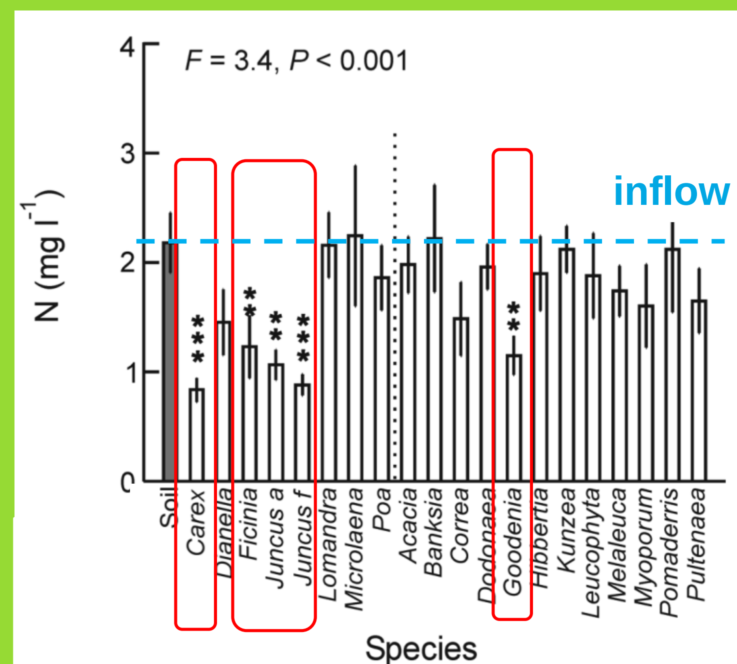
Essential Components

Inflow	Delivers stormwater into biofilter
Overflow	Allows high flows to bypass to avoid damage to system
Ponding	(or detention zone) Increases treatment capacity by allowing stormwater to pond before infiltration
Vegetation	Serves multiple roles in water treatment via uptake, transformation to organic forms, carbon provision to microbes, transpiration reducing stormwater volume, stabilising media surface, helping to maintaining infiltration rates, provides cooling to surrounding environment, amenity and aesthetics. The microbial community associated with plant roots facilitates uptake, decomposition and transformation of stormwater pollutants and plant litter.
Filter media	Provides physical filtration of particulates, physiochemical pollutant removal processes such as adsorption, fixation, precipitation, supports vegetation growth and the infiltration of stormwater attenuates and reduces the magnitude of the outflow hydrograph (providing stream health benefits)
Transition layer	Coarse sand. Provides a bridging layer to prevent migration of fine particles from the upper filter media to the gravel drainage layer
Drainage layer	Gravel. Allows the system to drain, either into a collection pipe and outflow point or infiltration into surrounding soils, also provides higher porosity to temporarily store stormwater within the pore space
Unlined	Allows infiltration into surrounding soils, either for the entire or only part of the system
Pre-treatment	Collects coarse sediment and litter, helping to protect the biofilter itself from premature clogging and blockages, and facilitating maintenance. Recommended for all systems except those whose impervious catchment is <2ha in size without identifiable sediment sources, or systems only receiving roof runoff (Water by Design, 2014).

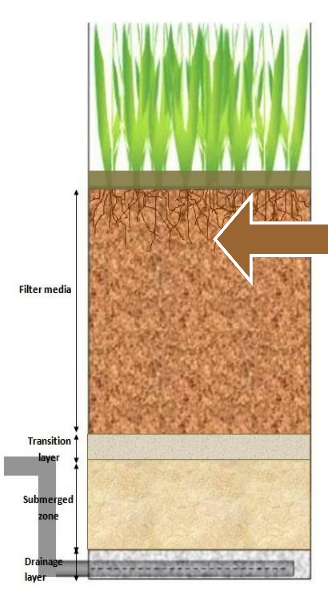
(1) Vegetation



Some plants are better than others



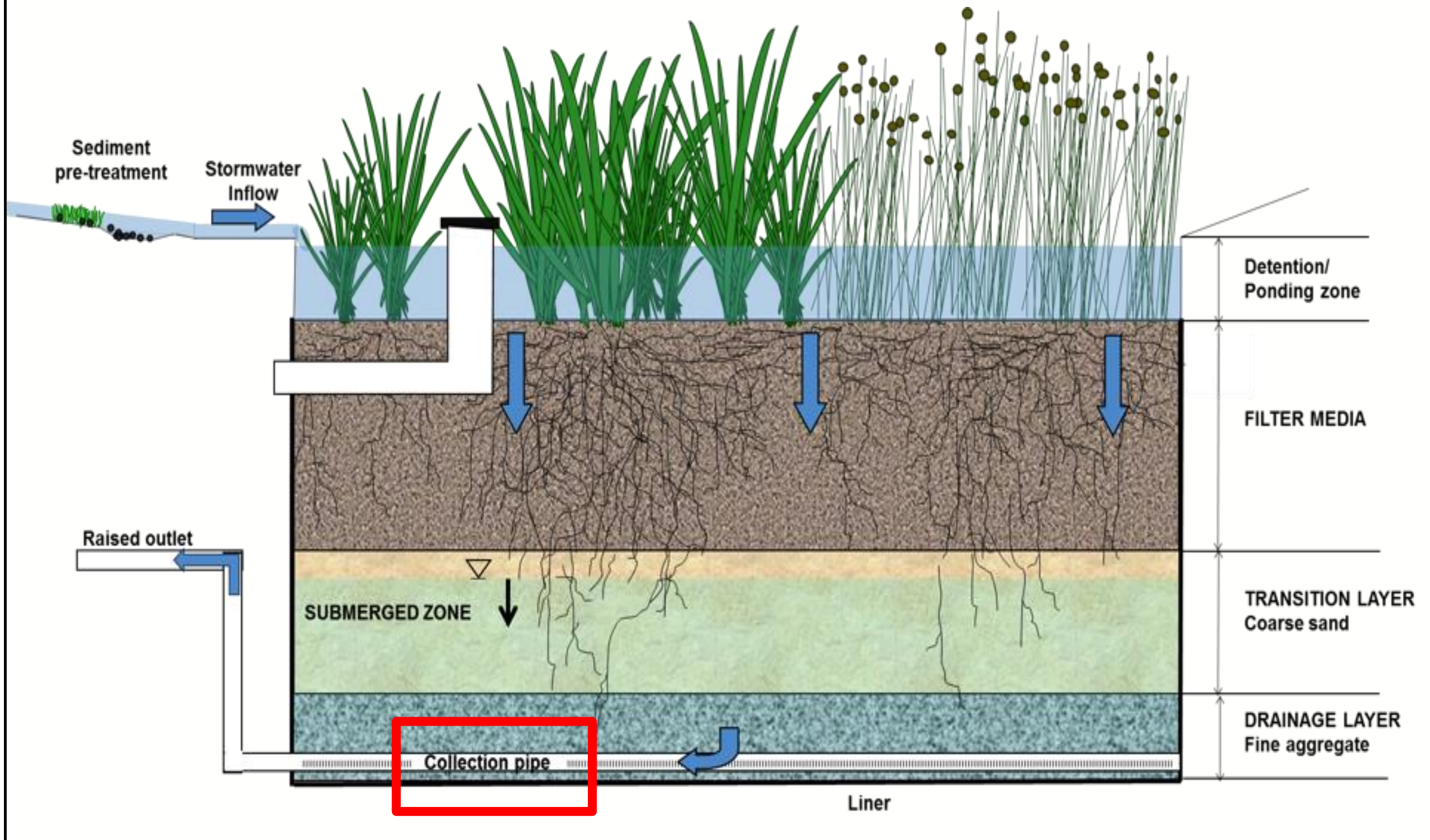
(2) Filter media - Soils



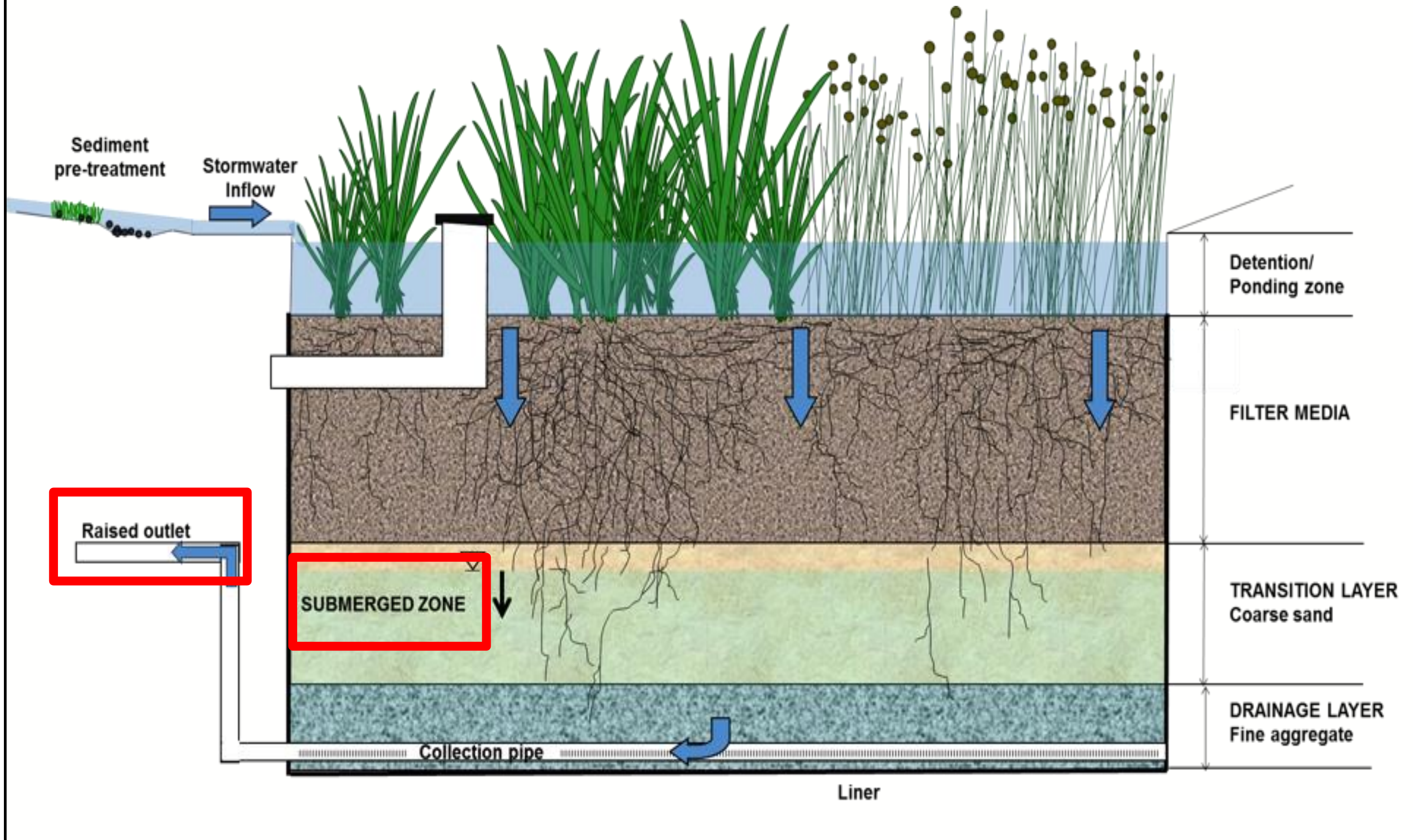
Soils sustain should have:

- **high infiltration rate**
- **low level of nutrients**

Additional Components



Additional Components



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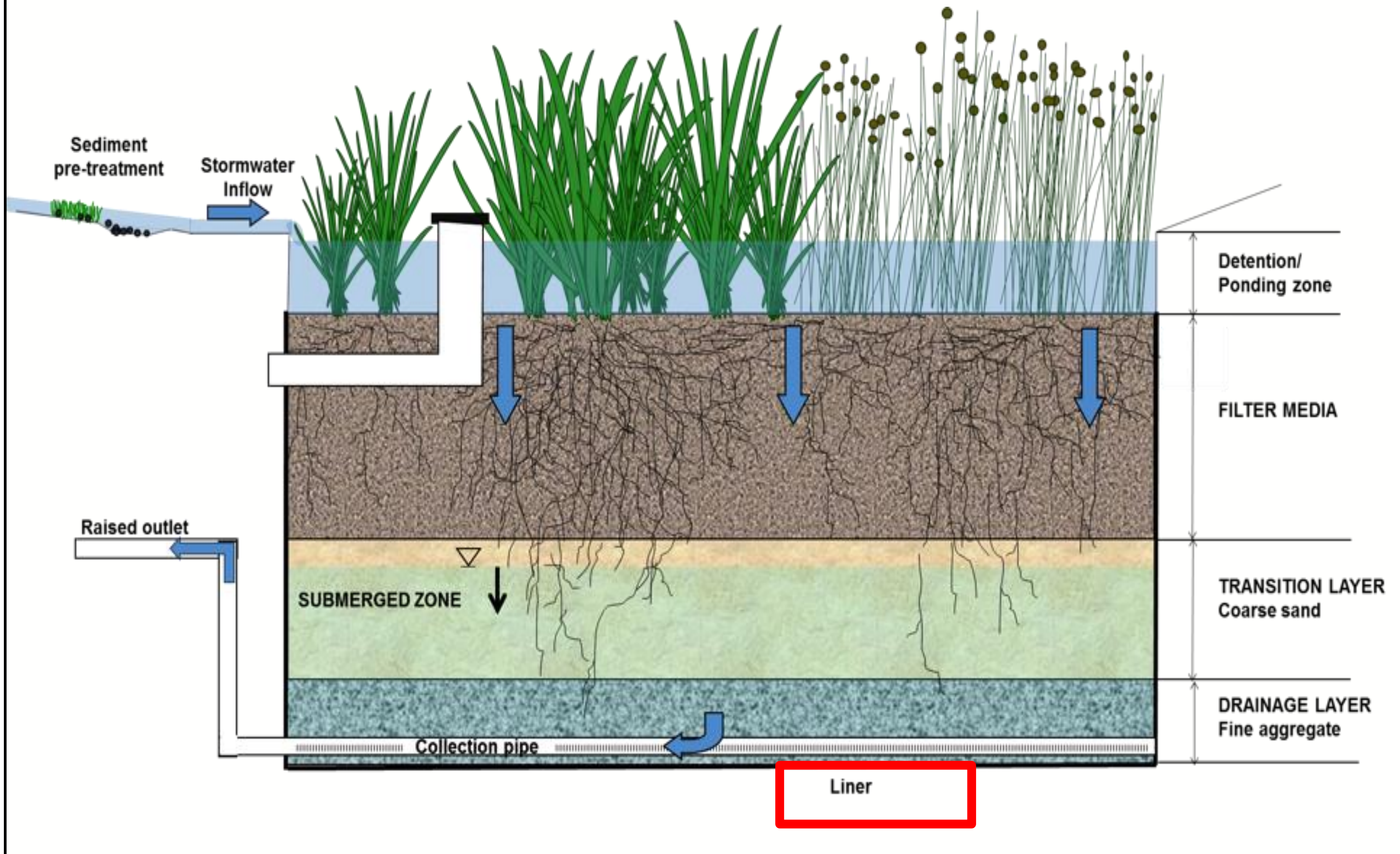

Additional Components

Collection pipe	Underdrain formed with slotted pipe and used to drain and collect effluent from the system. May not be needed for small systems or those with only exfiltration and no outflow pipe.
Raised outlet; creates temporary submerged zone	Strongly recommended, providing multiple benefits for water treatment and plant survival. Allows ponding in the lower portion of the biofilter, increasing moisture availability for plants and providing larger retention capacity for the temporary storage of stormwater. If the system is unlined, the raised outlet promotes exfiltration and creates a temporary submerged zone. Alternatively, if combined with an impermeable liner, it provides a longer-lasting submerged zone which benefits nitrogen removal via denitrification.
Submerged zone (or Saturated zone)	Created using a raised outlet, but may be temporary (if system unlined) or longer-lasting (if lined). Serves multiple roles: i.) provides a water supply to support plant and microbial survival across dry periods; ii.) benefits nitrogen removal, particularly following dry periods; iii.) provides anaerobic conditions for denitrification; iv.) provides prolonged retention for a volume of stormwater – which allows longer processing time.
Liner; creates long-lasting submerged zone	Prevents infiltration and may fully or only partially line the system
Carbon source	(wood chips) Mixed throughout the submerged zone when a liner is present. As the carbon source decomposes, it provides electrons to drive denitrification

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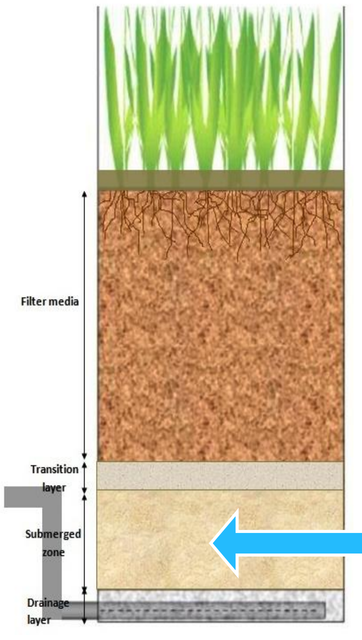
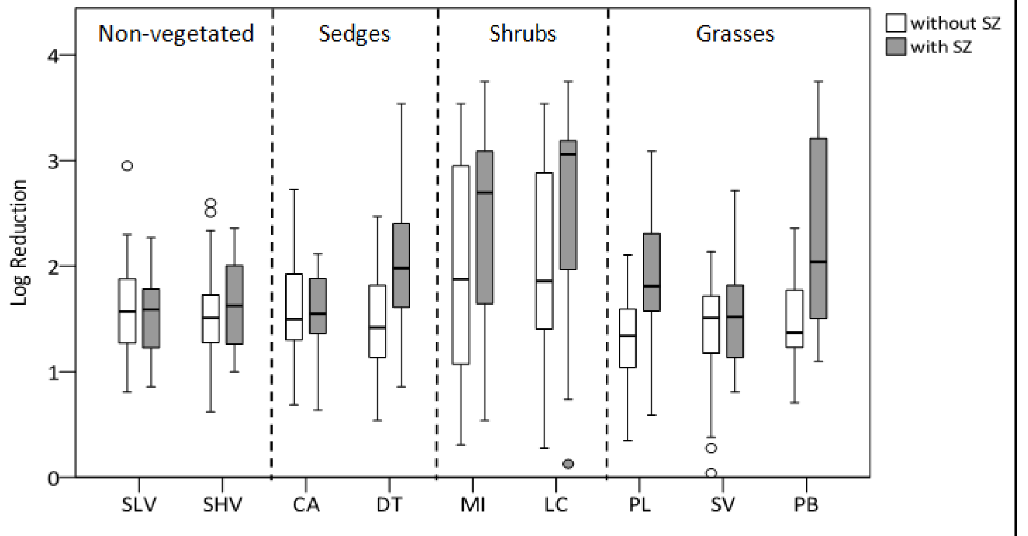
(3) Submerged Zone





Submerged Zone is important for passive watering of plants and removal of pollutants

Sizing

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Meeting different objectives

Waterways Protection

Nutrients

- ✓ Plants are essential: select at least 50% of species for effective removal
- ✓ Minimise nitrogen & phosphorus content in filter media to avoid leaching
- ✓ Include a raised outlet and liner to create a submerged zone, particularly in dry climates

Sediment

- ✓ Protect biofilter from high sediment loads (e.g. during construction) using temporary or permanent measures (e.g. pre-treatment)
- ✓ Size the system appropriately to avoid a shortened lifespan from clogging: Area = 2% of impervious catchment (Melbourne climate) or 4% (Brisbane).

Heavy Metals

- ✓ Organic matter binds metals, but high content compromises nutrient removal and infiltration
- ✓ Iron removal optimal with a larger biofilter area (≥4%) and use of effective plants (*Carax*).

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Meeting different objectives

Waterways Protection

Pathogens

- ✓ Use pathogen effective plant species (e.g. *Leptospermum continentale, Melaleuca incana, Carex appressa).*
- ✓ Include a raised outlet and liner to create a submerged zone which provides prolonged retention for die-off and adsorption to occur.
- ✓ Some drying is beneficial, but beyond 2 weeks drying performance is adversely affected. Top-up the level of the submerged zone during prolonged dry periods.
- ✓ Successive inflow events (back-to-back) also lead to poor treatment.
- ✓ Subject to further testing: consider use of a novel antimicrobial media (heat-treated copper-coated Zeolite) to enhance pathogen removal.

Flow Management

- ✓ Maximise biofilter treatment capacity via increased area, media depth or hydraulic conductivity of media (but within recommended range).
- ✓ Promote infiltration if conditions are suitable (e.g. unlined, partially lined or bioinfiltration design).
- ✓ Consider including a submerged zone to retain a proportion of runoff.
- ✓ Maximise evapotranspiration loss by maximising the biofilter area and using a dense planting.

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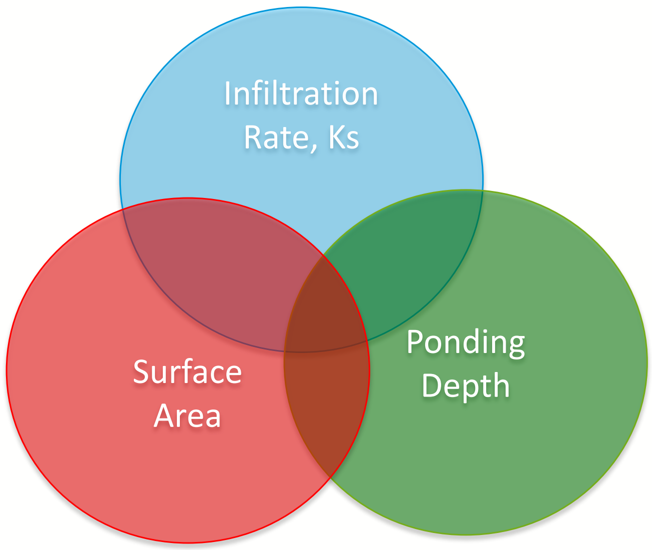
Meeting different objectives

Stormwater harvesting	
Pathogen, sediment, heavy metals and organic micro-pollutants may be key objectives (see Appendix D of the Biofilter Adoption Guidelines v2 (CRCWSC, 2015)). Nutrient removal may not be important if re-use for irrigation purposes.	
Maximise pathogen removal & yield	• Design to co-optimise for yield and to meet ecosystem protection objectives – generally line the system but balance with stormwater storage and demand patterns to achieve desired discharge reduction. • Use good species for pathogen removal. • Use media types that are effective for removal of pathogens (see Appendix D, but note that the use of this new, novel antimicrobial media requires care, as field testing is yet to be completed).

Meeting different objectives

Additional	
Biodiversity	• Use a diverse mixture of local native species.
Microclimate	• Include trees to provide shading and cooling via evapotranspiration. • Locate in urban zones lacking green spaces e.g. streets and car parks.
Amenity, aesthetics & community engagement	• Use species and landscaping that manifest compatibility with local surroundings (see below for further guidance). • Include a raised outlet to retain more moisture to support green and lush plant growth. • Engage with the community and communicate the function of the system through design (e.g. signage), and encourage the public to view and walk alongside the biofilter. • As far as practicable, keep the biofilter tidy, well-tended and green – design for low-level maintenance.
Habitat	• Use flowering species to promote birds and insects, and native plants from nearby habitat patches.

Sizing the system



Systems must be designed in an integrated way considering all 3 factors!

✓ Avoid under-sizing: System should be > 1% of its impervious surface catchment area as precaution to clogging!

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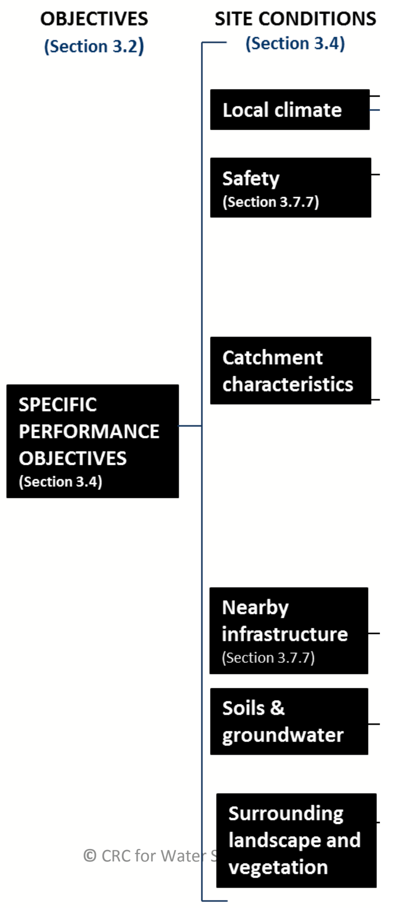
Key design decisions and tips to adapt to site conditions and performance requirements

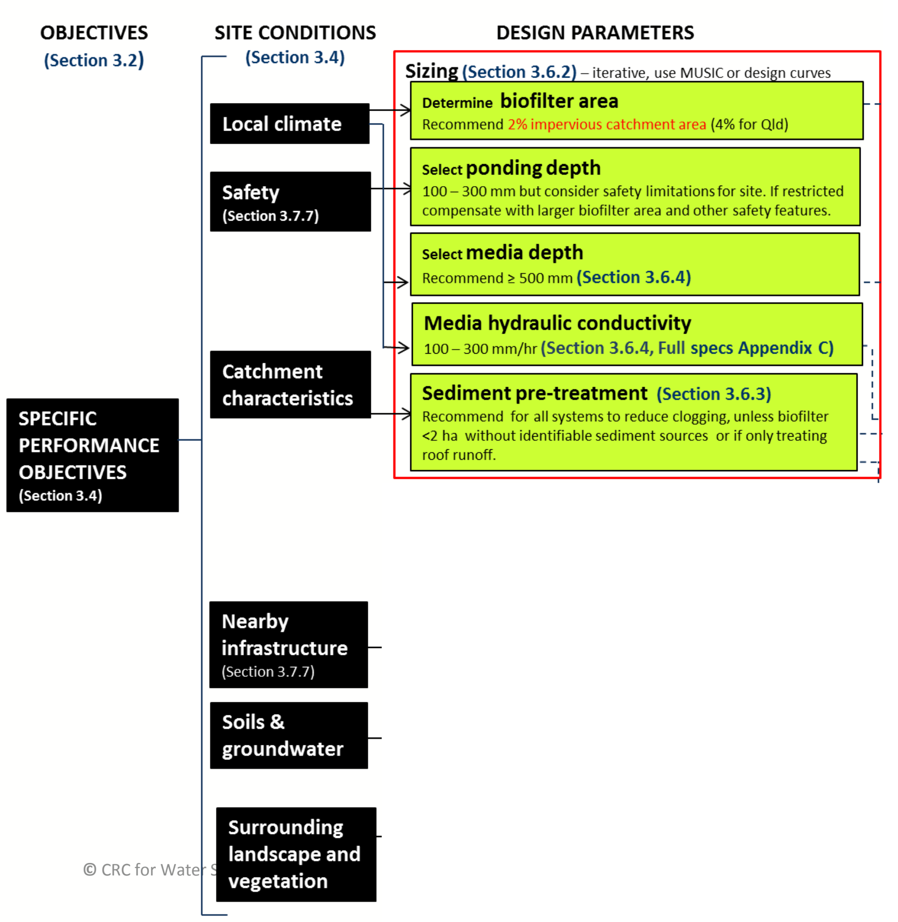
OBJECTIVES
(Section 3.2)

SPECIFIC PERFORMANCE OBJECTIVES
(Section 3.4)

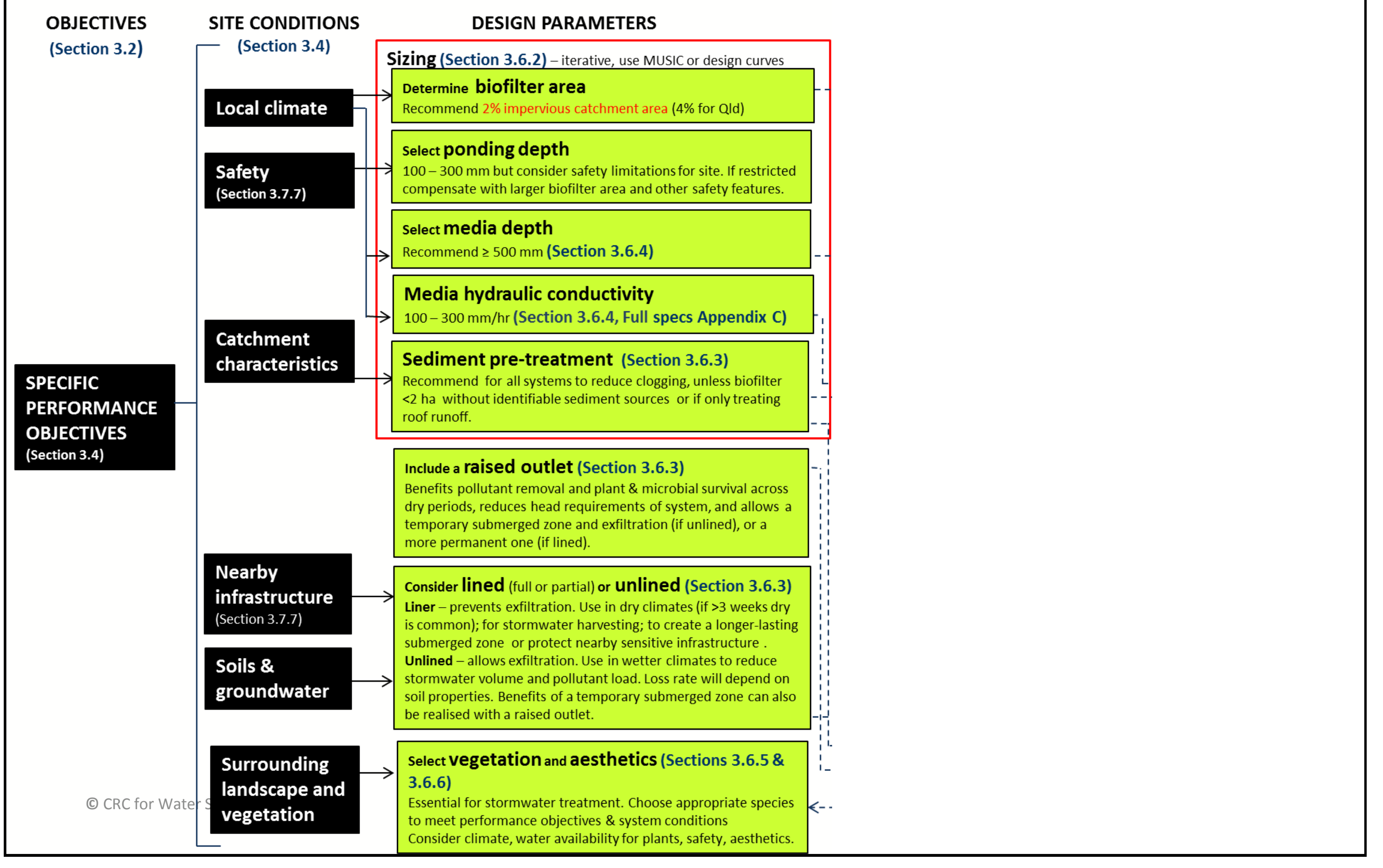
Key design decisions and tips to adapt to site conditions and performance requirements



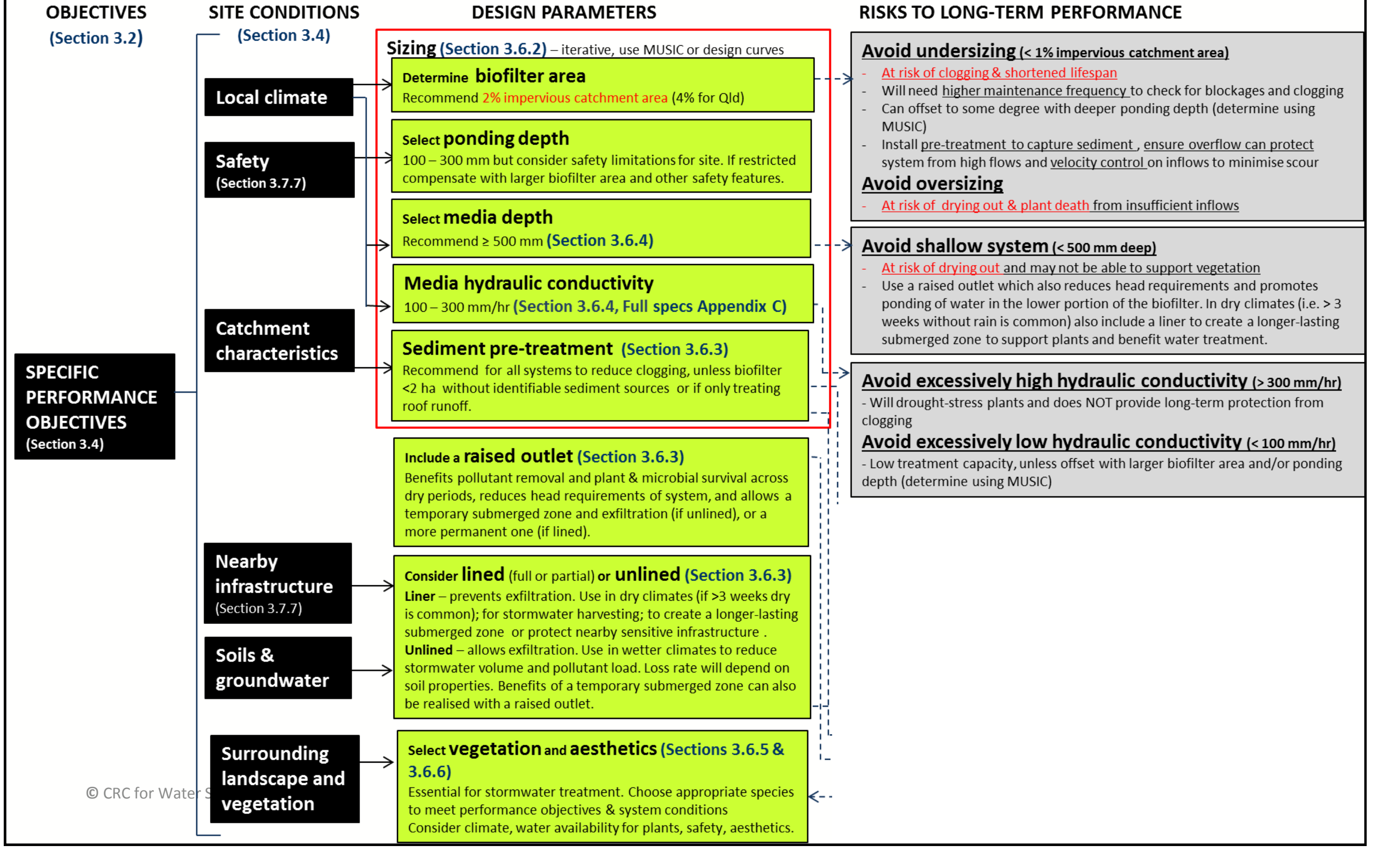
Key design decisions and tips to adapt to site conditions and performance requirements



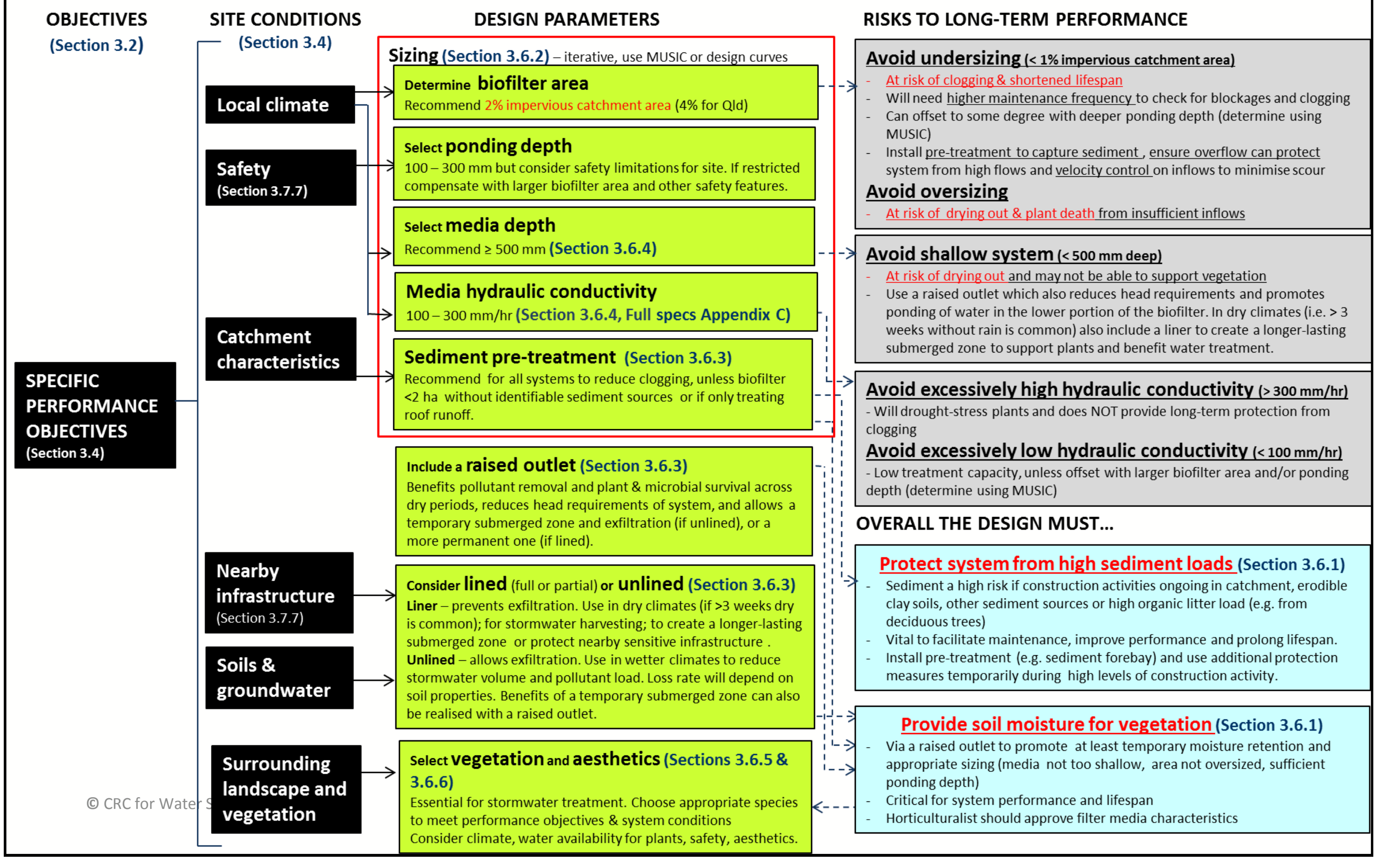
Key design decisions and tips to adapt to site conditions and performance requirements



Key design decisions and tips to adapt to site conditions and performance requirements



Key design decisions and tips to adapt to site conditions and performance requirements



Media (Soil) Specifications

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Characteristics of good media:

1. Should have sufficient infiltration rate (hydraulic conductivity)
   - Ks = 100-600 mm/h
2. Should not leach nutrients – have low nutrient content
   - Total Nitrogen (TN) < 1000 mg/kg
   - Available phosphate (Colwell) < 80 mg/kg
3. Must support plant growth – should have some fines
4. Must have stable structure – no dispersive clays
5. Often has layered structure but NO geofabrics between the layers

Incorrect media spec is the key cause for poorly functioning systems

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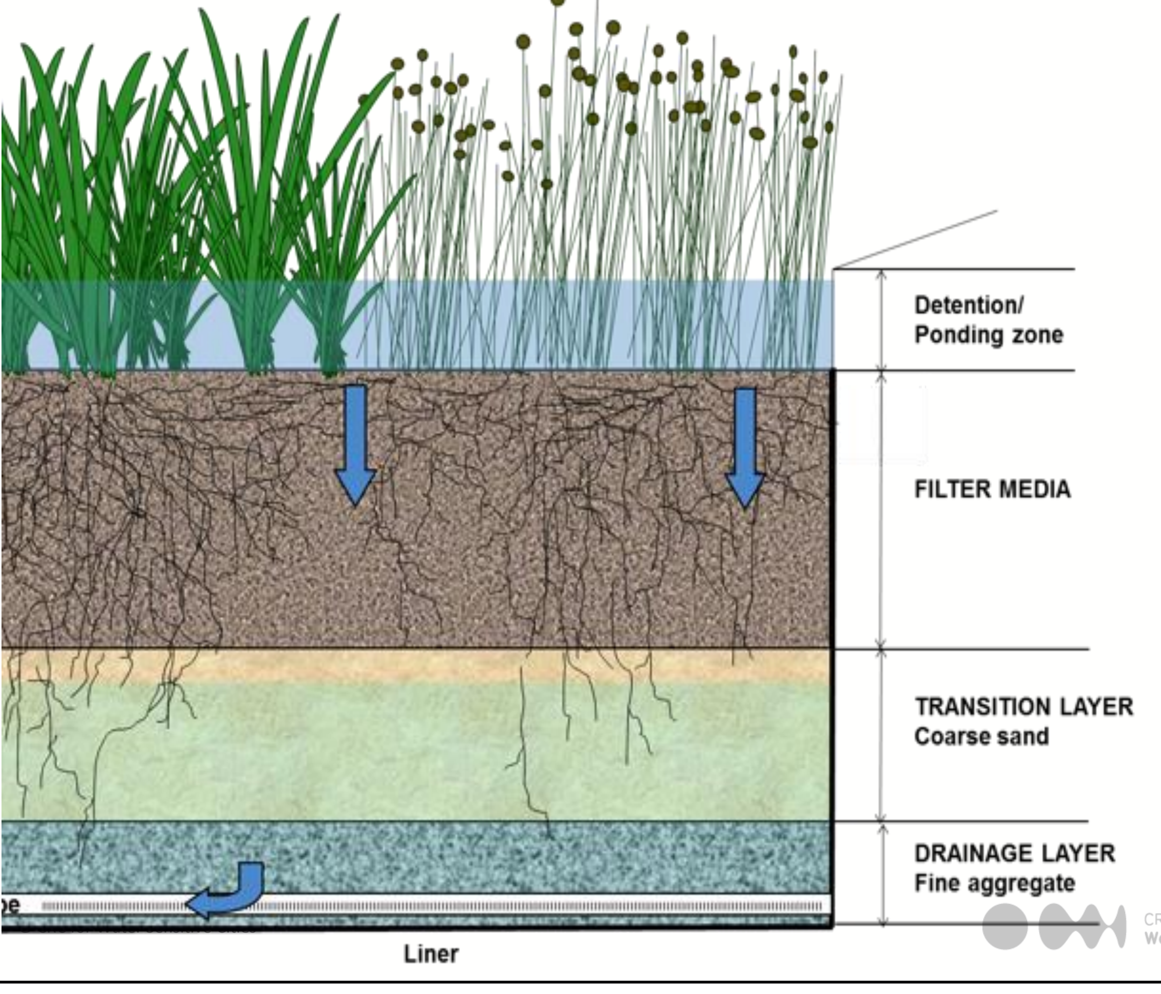
Media Layers: Table 3



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Essential Filter Media Spec

	Property	Specification to be met	Why is this important to biofilter function?
Filter Media (top layer/ growing media)			
ESSENTIAL SPECIFICATIONS	Material	Either an engineered material – a **washed, well-graded sand** – or naturally occurring sand, possibly a mixture	Media must be sand-based (and not a loam) to ensure adequate hydraulic conductivity, low nutrient content and structural stability
	Hydraulic conductivity	**100 – 300 mm/hr** (higher in tropical regions but must be capable of supporting plant growth). Determine using ASTM F1815-11 method	Provides adequate capacity to treat a higher proportion of incoming stormwater Testing method best represents field conditions
	Clay & silt content	**< 3% (w/w)**	Above this threshold hydraulic conductivity is substantially reduced. Too many very fine particles also reduce structural stability leading to migration and leaching
	Grading of particles	**Smooth grading** – all particle size classes should be represented across sieve sizes from the 0.05mm to the 3.4mm sieve (as per ASTM F1632-03(2010)	Provides a stable media, avoiding structural collapse from downwards migration of fine particles
	Nutrient content	**Low nutrient content** Total Nitrogen **(TN) < 1000 mg/kg** Available phosphate (Colwell) **< 80 mg/kg**	Prevents leaching of nutrients from the media
	Organic matter content	**Minimum content ≤ 5%** to support vegetation	Although some organic matter helps to retain moisture for vegetation and can benefit pollutant removal, higher levels will lead to nutrient leaching
	pH	**5.5 – 7.5** – as specified for 'natural soils and soil blends' in AS4419 – 2003 (pH 1:5 in water)	To support healthy vegetation over the long-term – without which the biofilter cannot function effectively
	Electrical conductivity	**< 1.2 dS/m** – as specified for 'natural soils and soil blends' in AS4419 – 2003	
	Horticultural suitability	Assessment by horticulturalist – **media must be capable of supporting healthy vegetation.** Note that additional nutrients are delivered with incoming stormwater	

Guidance for Filter Media Spec

	Property	Specification to be met	Why is this important to biofilter function?
GUIDANCE	Particle size distribution (PSD)	Note that it is most critical for plant survival to ensure that the fine fractions are included (% w/w) / Retained **Clay & silt** < 3% (< 0.05 mm) **Very fine sand 5-30% (0.05-0.15mm)** Fine sand 10-30% (0.15-0.25 mm) Medium sand 40-60% (0.25-0.5 mm) Coarse sand < 25% (0.5-1.0 mm) Very coarse sand 0-10% (1.0-2.0mm) Fine gravel < 3% (2.0-3.4 mm)	Of secondary importance compared with hydraulic conductivity and grading of particles, but provides a starting point for selecting appropriate material with adequate water-holding capacity to support vegetation. **Filter media do not need to comply with this particle size distribution to be suitable for use in biofilters**
	Depth	400-600 mm or deeper	To provide sufficient depth to support vegetation Shallow systems are at risk of excessive drying
	Once-off nutrient amelioration	Added manually to top 100 mm **once only** Particularly important for engineered media	To facilitate plant establishment, but in the longer term incoming stormwater provides nutrients
	Submerged zone	Strongly recommended, particularly if entirely engineered media is used, filter media has a relatively high hydraulic conductivity or a shallow depth	To provide water retention to support plants through dry periods, and greater pollutant removal

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Essential Transition Layer Spec

Transition sand (middle layer)			
ESSENTIAL SPECIFICATIONS	**Material**	**Clean well-graded sand e.g. A2 Filter sand**	Prevents the filter media washing downwards into the drainage layer
	Hydraulic conductivity	**Must be higher than the hydraulic conductivity of the overlying filter media**	To allow the system to drain and function as intended
	Fine particle content	< 2%	To prevent leaching of fine particles
	Particle size distribution	Bridging criteria – the smallest 15% of sand particles must bridge with the largest 15% of filter media particles (Water by Design, 2009) (VicRoads, 2004): **D_{15} (transition layer) ≤ 5 x D_{85} (filter media)** *<u>where</u>: D_{15} (transition layer) is the 15^{th} percentile particle size in the transition layer material (i.e.,15% of the sand is smaller than D_{15} mm), and D_{85} (filter media) is the 85^{th} percentile particle size in the filter media* The best way to compare this is by plotting the particle size distributions for the two materials on the same soil grading graphs and extracting the relevant diameters (Water by Design, 2009)	To avoid migration of the filter media downwards into the transition layer
		Bridging criteria **only in designs where transition layer is omitted** (Water by Design, 2009; VicRoads, 2004): D_{15} (drainage layer) ≤ 5 x D_{85} (filter media) D_{15} (drainage layer) = 5 to 20 x D_{15} (filter media) D_{50} (drainage layer < 25 x D_{50} (filter media) D_{60} (drainage layer) < 20 x D_{10} (drainage layer)	To avoid migration of the filter media into the drainage layer only in the case where a transition layer is not possible.

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Essential Drainage Layer Spec

	Property	Specification to be met	Why is this important to biofilter function?
Drainage layer (base)			
ESSENTIAL SPECIFICATIONS	**Material**	**Clean, fine aggregate - 2-7 mm washed screenings (not scoria)**	To collect and convey treated stormwater, protect and house the underdrain (if present), or provide a storage reserve as part of a submerged zone, or prior to exfiltration (in unlined systems).
	Hydraulic conductivity	**Must be higher than the hydraulic conductivity of the overlying transition layer**	To allow the system to drain and function as intended
	Particle size distribution	Bridging criteria D_{15} (drainage layer) ≤ 5 x D_{85} (transition media) *<u>where</u>: D_{15} (drainage layer) - 15^{th} percentile particle size in the drainage layer material (i.e., 15% of the aggregate is smaller than D_{15} mm), and D_{85} (transition layer) - 85^{th} percentile particle size in the transition layer material*	To avoid migration of the transition layer into the drainage layer
	Perforations in underdrain	Perforations must be small enough relative to the drainage layer material Check: D_{85} **(drainage layer) > diameter underdrain pipe perforation**	To prevent the drainage layer material from entering and clogging the underdrainage pipe (if present)
G.	**Depth**	Minimum 50 mm cover over underdrainage pipe (if present)	To protect the underdrain from clogging

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Questions?

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Role and Selection of Plants and Submerged Zone

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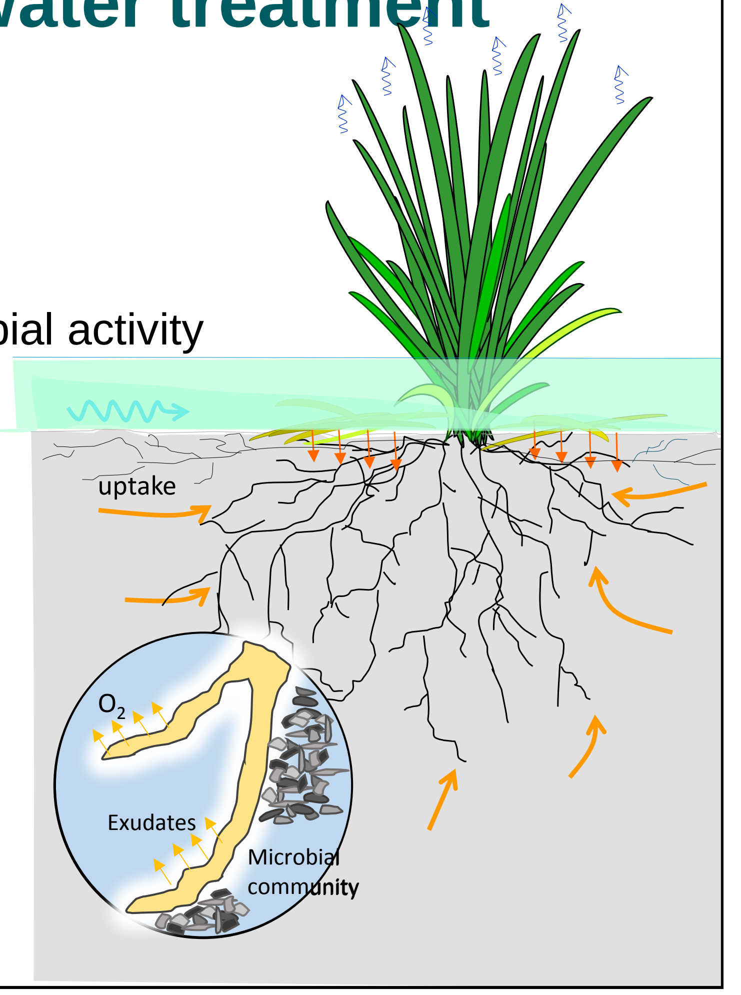
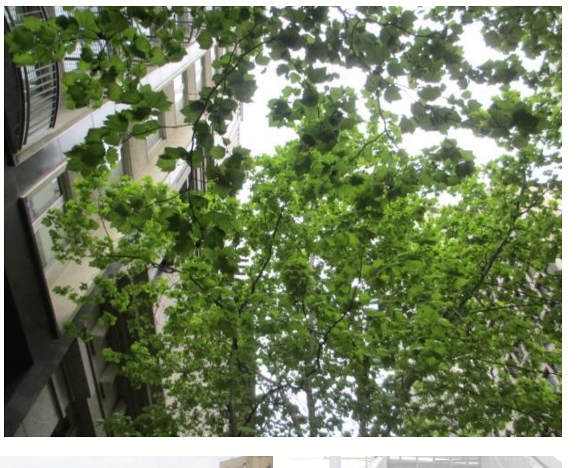
Roles of plants in water treatment

- Nutrient uptake
- Conversion into organic forms
- Return via litter
- Provide carbon to drive microbial activity
- Oxygenate the rhizosphere
- Slow and disperse flow
- Stabilise the media
- Evapotranspiration loss
- Maintain infiltration



Additional benefits of biofilter vegetation

- Aesthetics
- Green spaces
- Human health
- Microclimate
- Economic
- Biodiversity

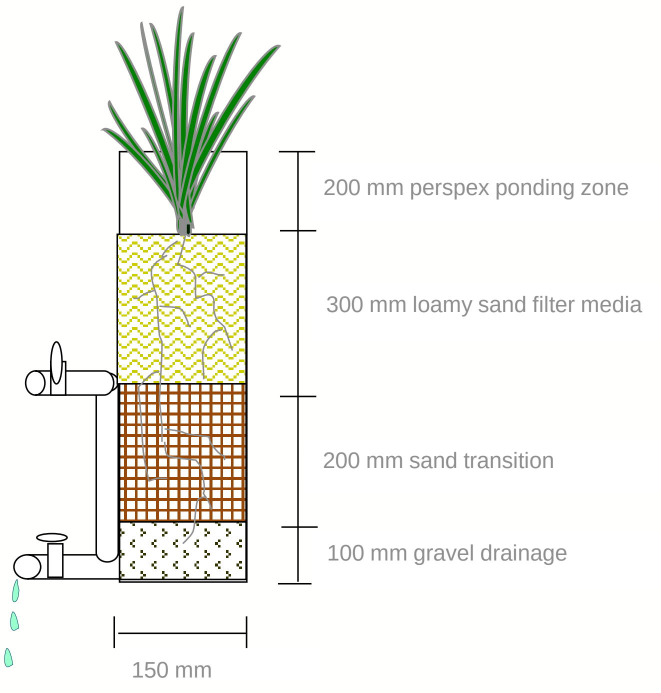


Role of the submerged zone

- Support vegetation health & function during dry conditions
- Enhance pollutant removal, particularly nitrogen
- Longer retention of water
- Greater performance consistency

Experiment

- 245 biofilter columns
- 22 plant species
  - Australian natives from two states (Vic & WA)
  - 2 lawn grasses
- Non-vegetated controls
- 2 Outlet designs
  - Free draining
  - Submerged + carbon



Free draining

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Experiment

- 245 biofilter columns
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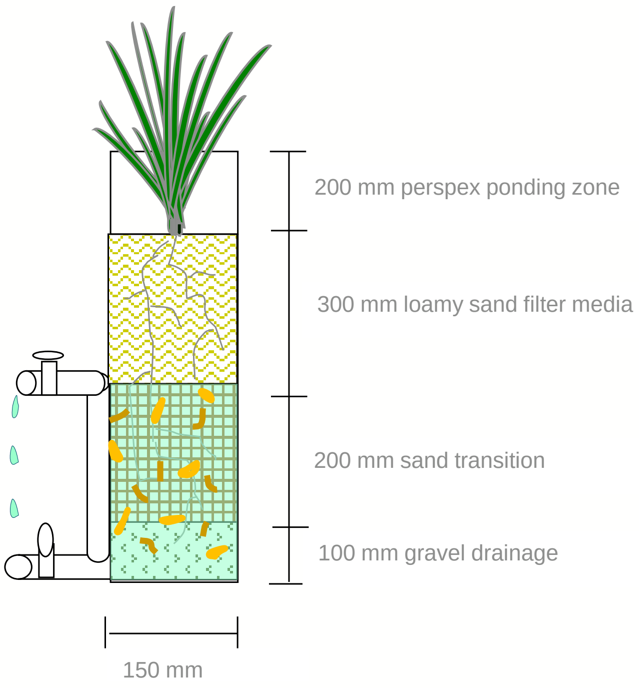

Submerged zone + C source

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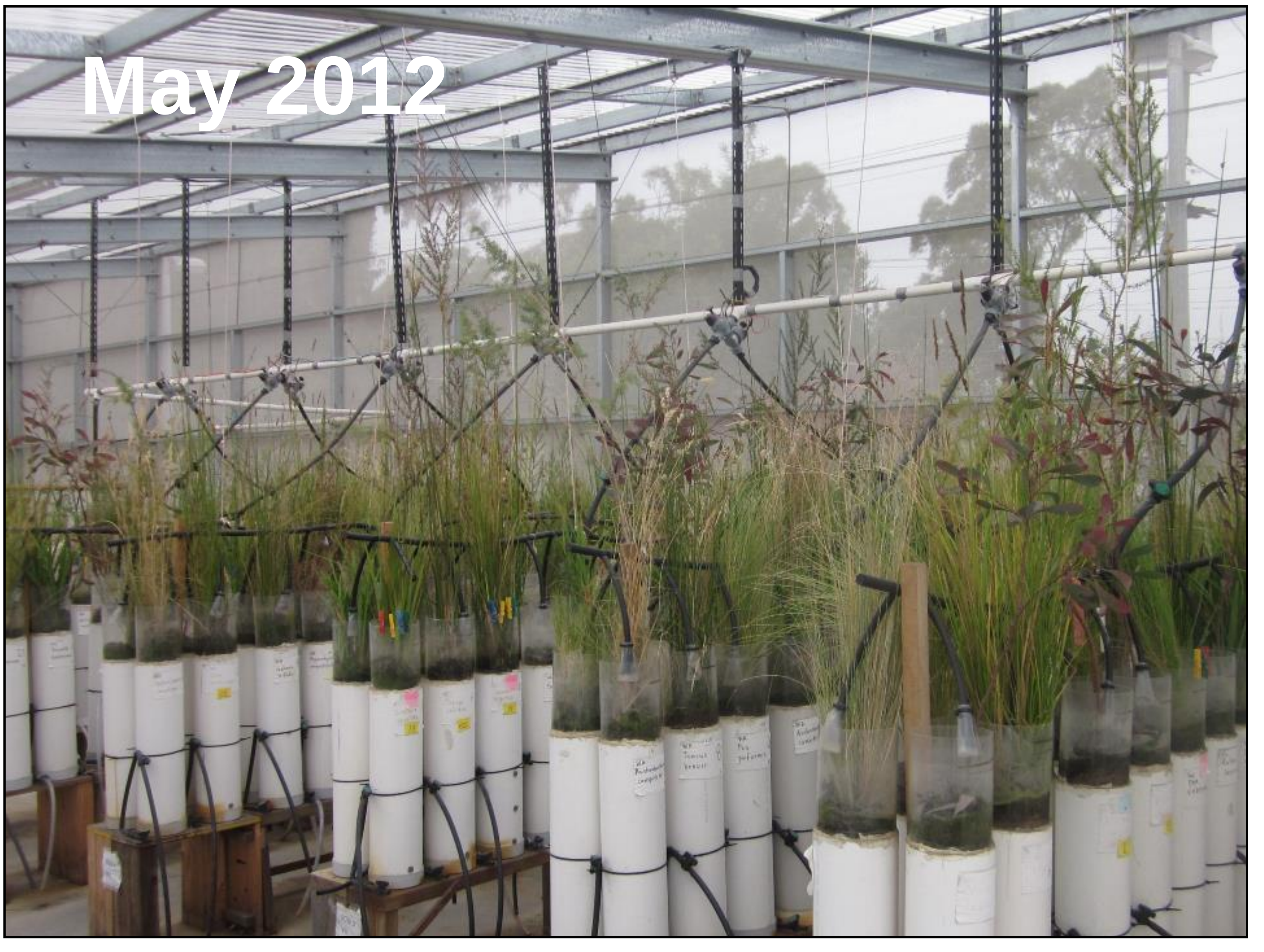
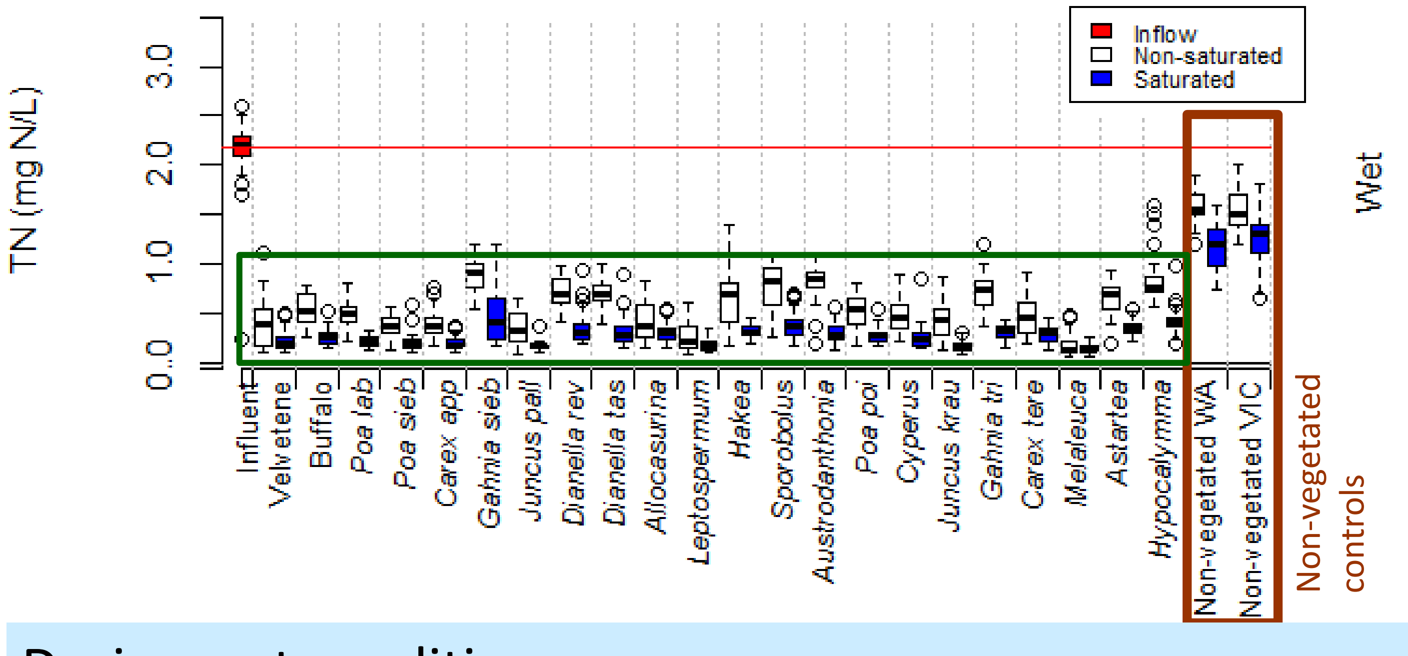


Total Nitrogen (TN)



During wet conditions –

- All plant species perform relatively well – significantly more effect than non-veg
- May be low nutrient media
- Submerged zone reduces species variation

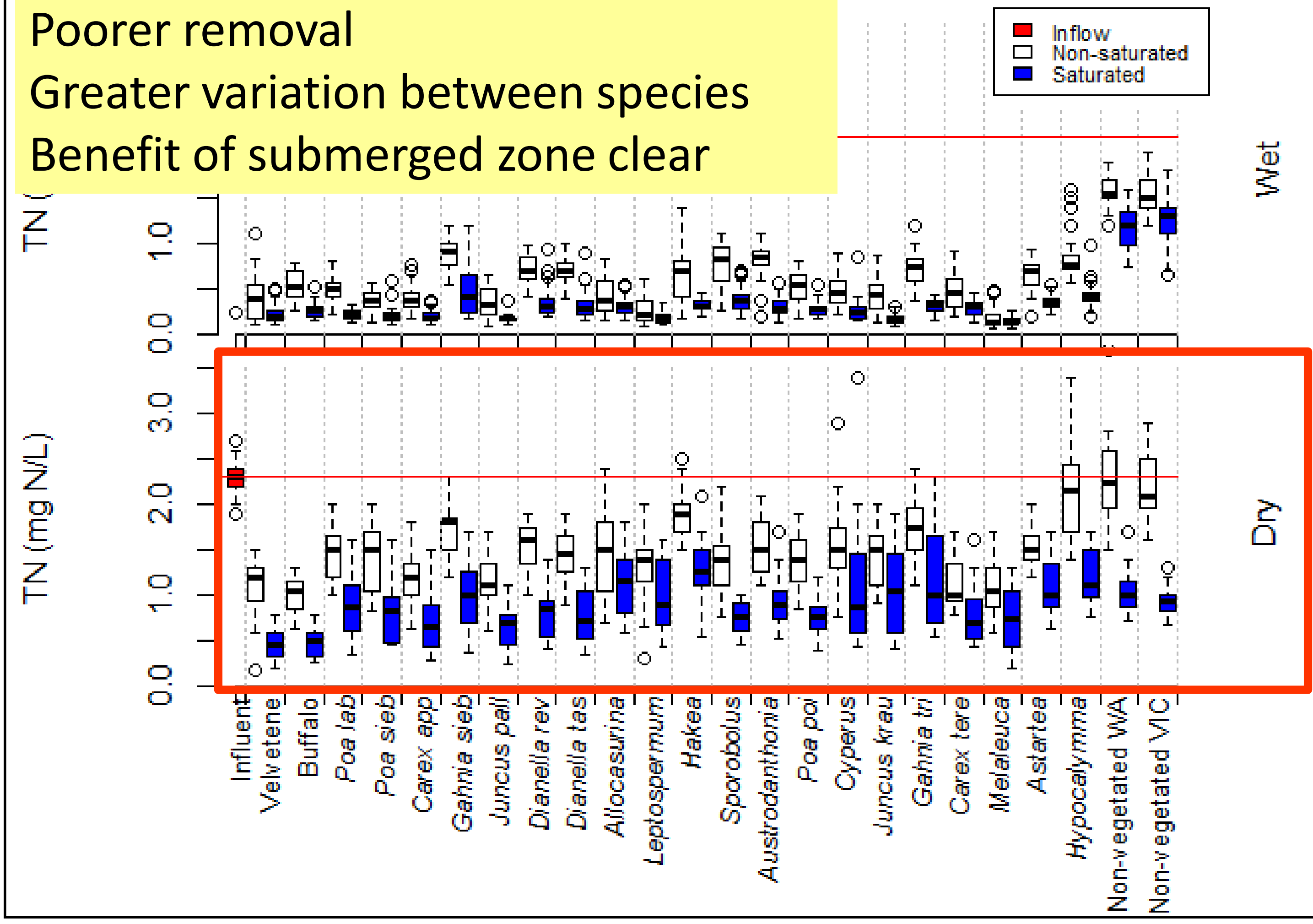
After drying…

Following drying –

Poorer removal

Greater variation between species

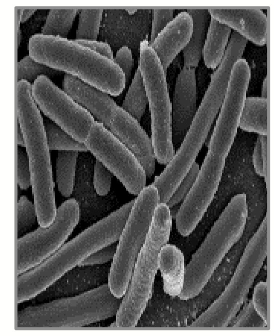
Benefit of submerged zone clear



Where does the nitrogen go?

vs

N_2, N_2O



NO_3^-, NH_4^+

NO_3^-

Assimilation

Denitrification

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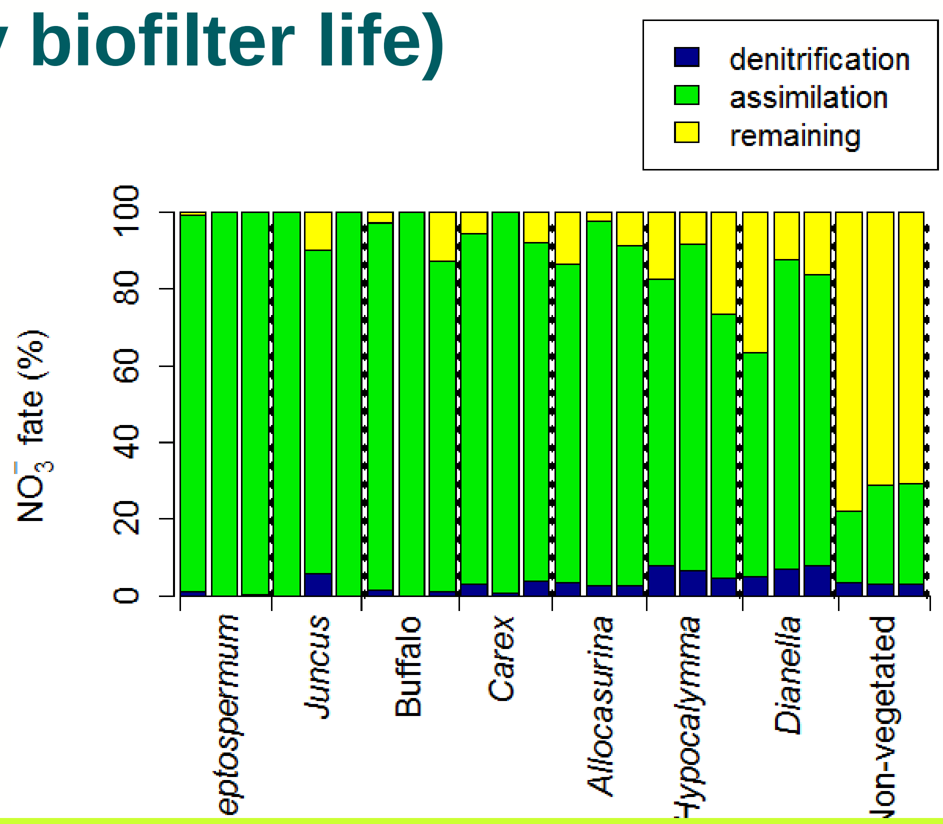
Division of incoming nitrate (early biofilter life)

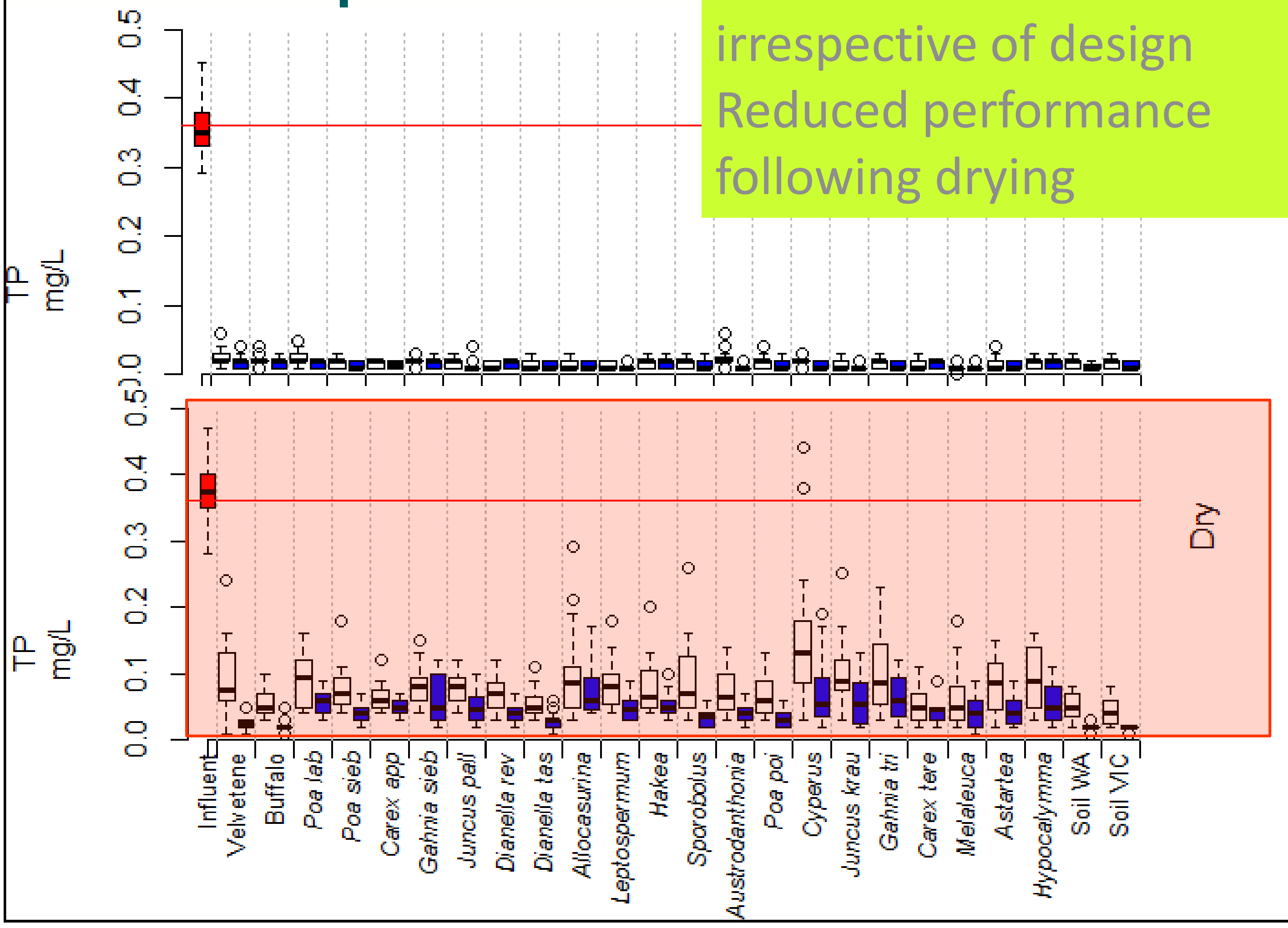


- Most nitrate is assimilated
- Denitrification minimal at this stage

Total Phosphorus

Effective removal in wet irrespective of design

Reduced performance following drying



Plant species selection for optimal nitrogen removal

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Role of plants in wet vs. dry

- **Variation in performance** between plant species **minimal** if inflows frequent and using low nutrient media
- **Wet conditions** - plants with high biomass and extensive roots superior performers
  - high N uptake capacity
- **Drying reversal** – low growth and biomass advantageous
  - may reflect lower evapotranspiration
  - species diversity or targeted planting
- Consistently effective species distinguished by extensive root system
- **Submerged zone**
  - mitigates drying effects
  - reduces species variation
  - treats pore water during inter-event period

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Submerged Zone

- The presence of a "permanently" submerged zone **>300 mm** made from **sand or gravel with a carbon source** (around 5% by volume) will:
  - Improve Cu and Zn removal (to meet ANZECC concentration targets)
  - Support plant survival during dry periods and therefore
  - Ensure TN removal after dry spells
- **Strongly recommended for all biofilters**, but especially where
  - Low rainfall and/or extended dry periods are common
  - Systems are unavoidably shallow or over-sized

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Submerged Zone Design

- Located within the transition and drainage layers
  - Create using an upturned pipe
- Unlined -> will be temporary
  - Appropriate in wet climates
- Lined -> longer lasting
  - Use in areas where >3 weeks dry weather is common
- Ideal depth is 450-500 mm
- Carbon source should be low nutrient
  - e.g. sugar cane mulch, pine chips (without bark), hardwood chips (6-10 mm)

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Submerged Zone – how long will it last?

$$t = \frac{d \times p}{ET}$$

t = drawdown time (days)

d = SZ depth (mm)

p = SZ porosity

ET = evapotranspiration (mm/day)

So, for a biofilter with a SZ depth of 450 mm and a SZ porosity of 0.39…

In January, Adelaide ET ~ 235 mm => 7.6 mm/day

$$t = \frac{450 \times 0.39}{7.6} \sim 23 \text{ days}$$

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Plant Selection

- Select species with **extensive and fine roots, high growth, total plant mass** and long stems/leaves
- **Some species perform relatively well in both wet and dry** (e.g. *Carex* spp., *Juncus pallidus* and *Melaleuca incana*), or **consistently poorly** (e.g. *Hypocalymma*, *Austrodanthonia*, *Astartea*, *Hakea* and *Gahnia* spp.)
- **Plant species with quite differing appearance can have similar performance and key morphological traits** -> may provide long-term functional capacity

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Plant Selection

- Similarity in broad plant type or general above-ground appearance is a poor guide e.g. *Carex* vs.*Gahnia*

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Plant Selection

- **Species in same genus** expected to have relatively similar performance
- **Compare species first to those of the same broad type** e.g. grasses with extensive and fine roots relative to other grasses may perform well.

Native grasses

Poa species (Medium)

Austrodanthonia (Poor)

Native trees

Melaleuca incana (Effective)

Hypocalymma (Poor)

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Lawn grasses

- Distinct morphology – suggests alternate mechanisms
- Promising, but need to consider:
  - Clogging potential
  - Maintenance issues – mowing effectively harvests biomass and removes N but media consolidation potential
  - Evapotranspiration loss on large scale

Practical Considerations

- Local context
- Local climate
- Stakeholder needs & expectations
- Available budget - including maintenance
- Natural vegetation
- Weed issues
- Public health & safety

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Practical Considerations

- Plant a mixture of species
  - More consistent function across seasons
  - Allow "self-select"
- Minimise surface layer drying
  - use species that provide surface cover/shade, divert other wastewater streams to provide baseflow, increase media water holding capacity (but maintain conductivity)
- pH and salt tolerance
- Root architecture
- Avoid annual species

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Trees

- Anecdotal evidence suggests the most successful, least "needy" systems are those that contain trees
- Pro: can shade and protect understorey species during extended dry periods
- Con: can shade out or outcompete understorey species
- Con: can have large and/or invasive root systems
- Avoid dropping fruit, limbs, leaves
- Not always appropriate
  - e.g. where it is necessary to maintain clear lines of sight

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Planting Density

- **A higher planting density** can help to
  - Reduce erosion
  - Reduce weed encroachment
  - Trap floating debris
- **Plant at a density that will result in almost complete surface coverage within 1 year**
  - Clumping sedges & rushes – 6-9 plants/m^2
  - Spreading sedges & rushes – 4-6 plants/m^2
  - Shrubs & trees (over sedges & rushes) – 1 plant/2 m^2 (small shrubs) or 1 plant/5 m^2 (larger trees)
- Increased capital costs but lower maintenance costs

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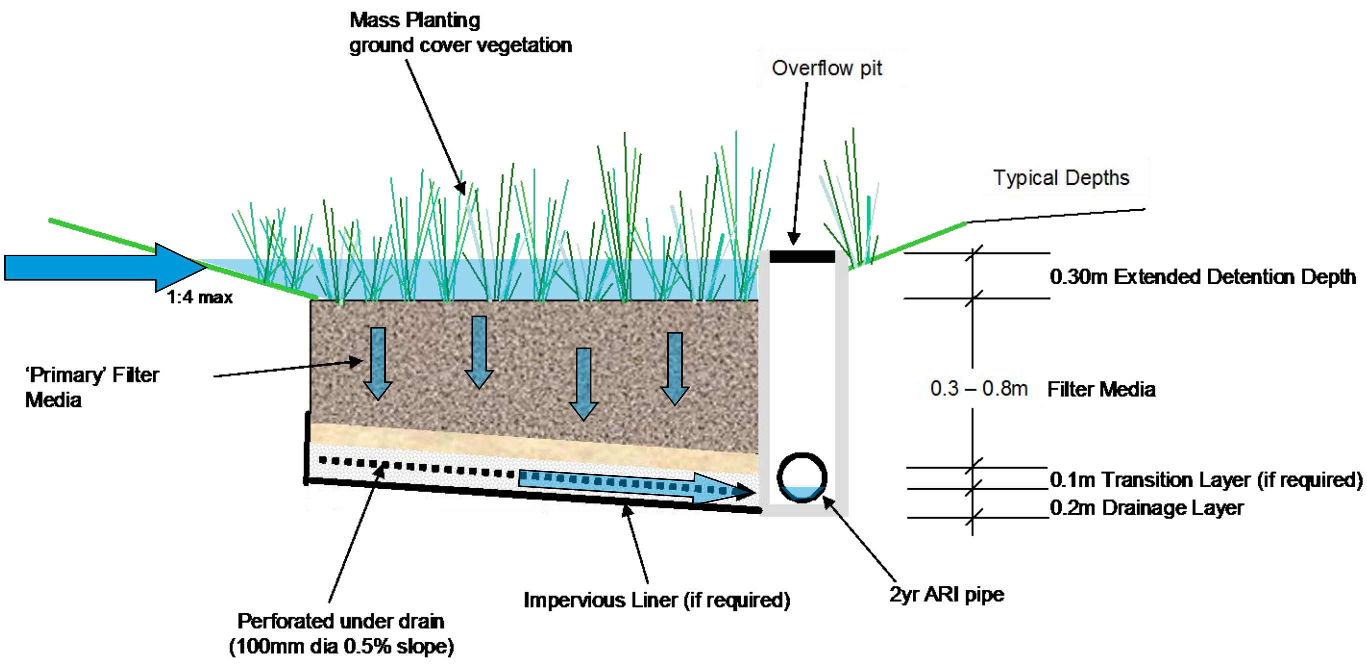
Planting Layout

- Why do we need to think about this?



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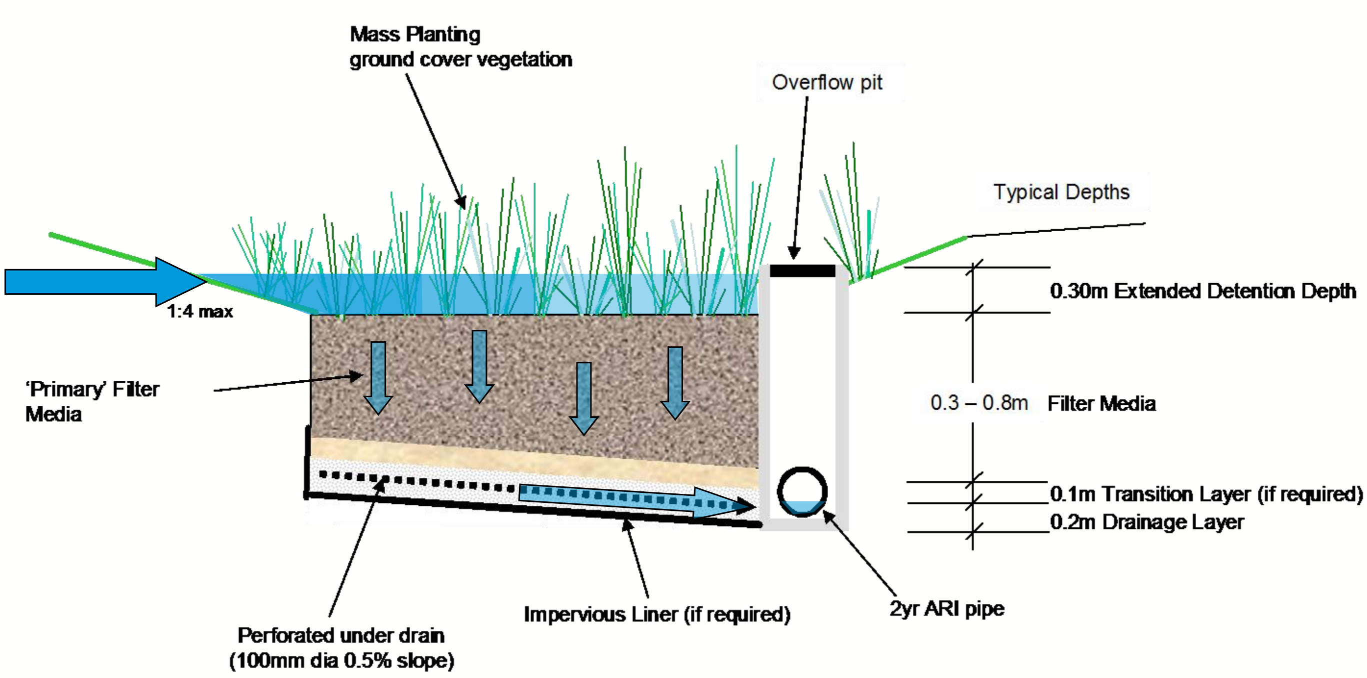
Planting Layout

- Why do we need to think about this?



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Planting Layout

- Range of conditions exist within a biofilter -> **take advantage of these micro-environments**
  - Plant species with favourable dry-climate characteristics (e.g. slower growth and low biomass) further from inlet / up batter slopes
  - Place species with advantageous wet-period traits (e.g. extensive and fine roots, high biomass) close to the inlet/ in depressions
  - If in doubt, choose a diversity of plant species
- To create a landscaping feature

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Plant Installation

- Best time to plant is June
  - Access to irrigation allows flexibility
- Order plants at least 6 months before planting
- Good quality stock increases likelihood of effective establishment
- Tubestock most effective & cost-efficient
  - Direct seeding generally not viable
  - Larger specimens may be necessary if instant effect desired
- Avoid mulch
  - Use high planting density instead

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Plant Establishment

- Regular monitoring & maintenance required for first 2 years
  - Monitoring can be a visual drive by
  - Irrigation increases establishment success
  - Protect vegetation from grazing, pedestrian & vehicle access, weeds, impacts of adjacent land-use
- Minimise maintenance requirements with
  - Good design
  - Preventative maintenance

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Questions?

Australian Government
Department of Industry and Science
Business
Cooperative Research
Centres Programme

Designing for Stormwater Harvesting

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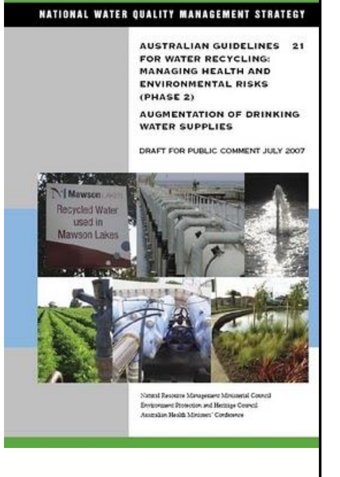
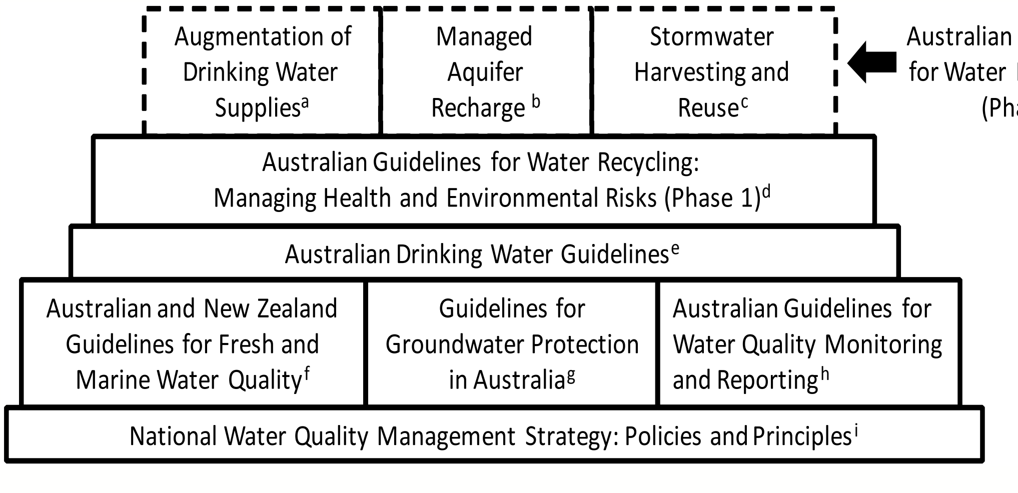
Stormwater harvesting guidelines



Guidelines for Water Recycling: Phase 2

- Augmentation of drinking water supplies (2008)
- Stormwater harvesting and reuse (2009) - http://www.ephc.gov.au/taxonomy/term/39
- Managed aquifer recharge (2009)



What is the target (additional to waterway protection)?

- Removal of pathogens
- Removal of heavy metals
- Removal of organic toxicants

Stormwater harvesting guidelines

Recommended removal of pathogens

Use	Required log reduction targets	Recommended treatment or access control	Log reduction achieved	Any extra criteria to be tested?
Restricted access irrigation (non food) (spray, drip, sub)	V 1.3, P 0.8, B 1.3	Restrict access during irrigation	2	No
Unrestricted access irrigation (non food)	V 1.3, P 0.8, B 1.3	Filtration and disinfection	>2.5	Yes, turbidity < 25NTU, E. coli <10/100mL
Irrigation of food crops	V 2.4, P 1.9, B 2.4	Filtration and disinfection	>2.5	Yes, turbidity < 25NTU, E. coli <1/100mL
Indoor/outdoor non potable	V 2.4, P 1.9, B 2.4	Filtration and disinfection	>2.5	Yes, turbidity < 25NTU, E. coli <1/100mL

Science Behind Good Stormwater Harvesting Design

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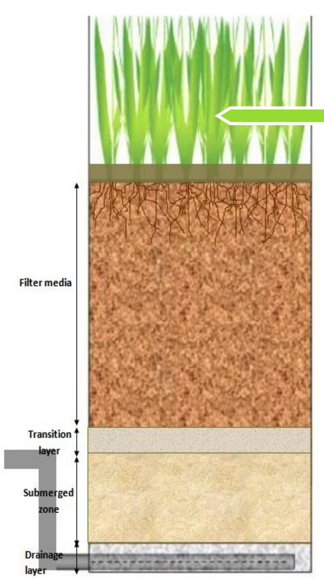
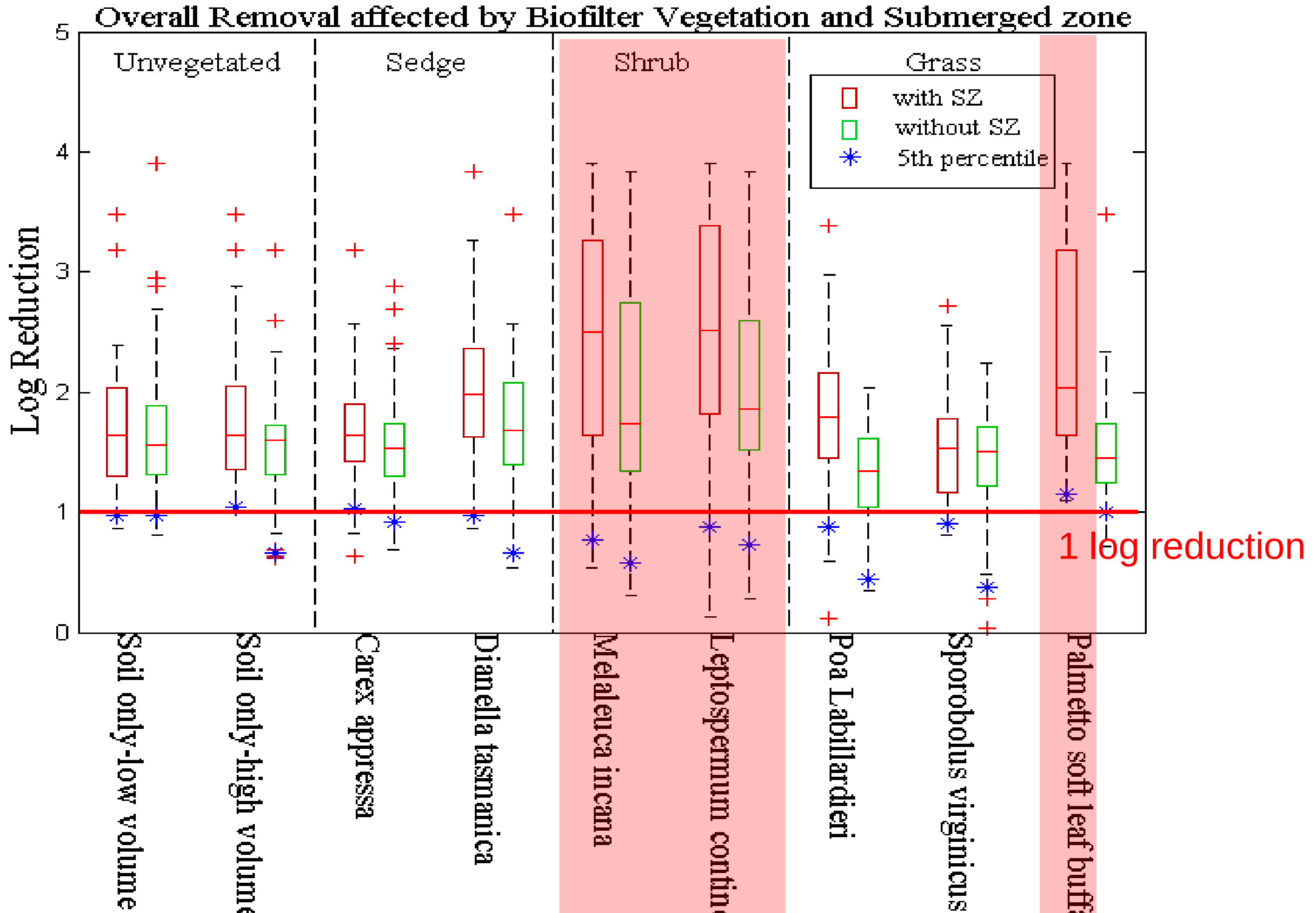
Key Design Characteristics:

(1) Vegetation



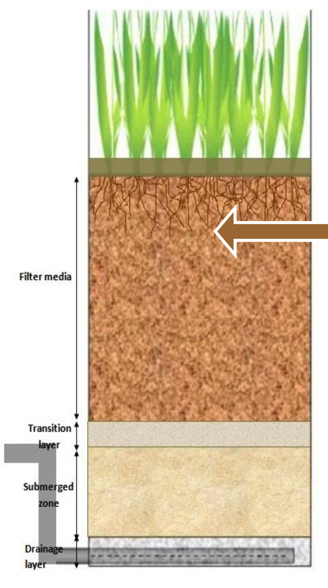
Some plants are better than others



E. coli Removal

Key Design Characteristics:

(2) Soils



Soils should include novel antimicrobial media

Novel Antimicrobial Zeolite Based Filter Median

ZCuCuO180

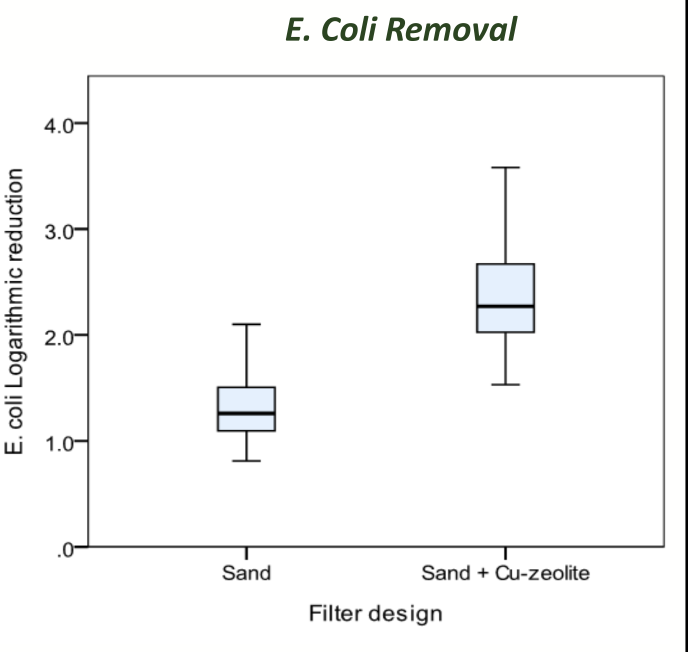
Zeolite coated by Copper and Copper Oxide cooked at 180oC

- Good removal and inactivation
- Cu leaching below drinking water guideline

ZCu400

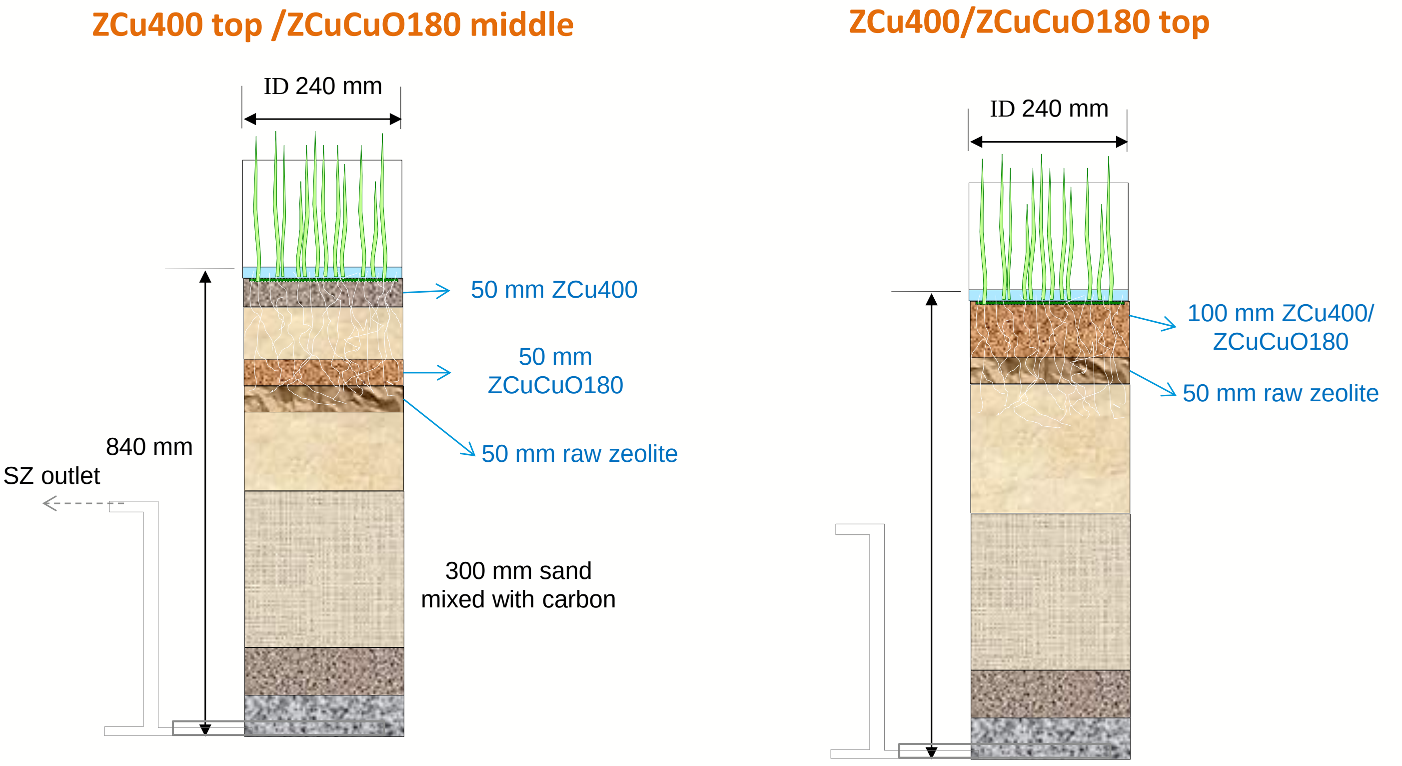
Zeolite coated by Copper and cooked at 400oC

- No obvious better removal but excellent inactivation
- Cu leaching below long-term irrigation guideline



95

Large Column Study of Novel-Biofilters

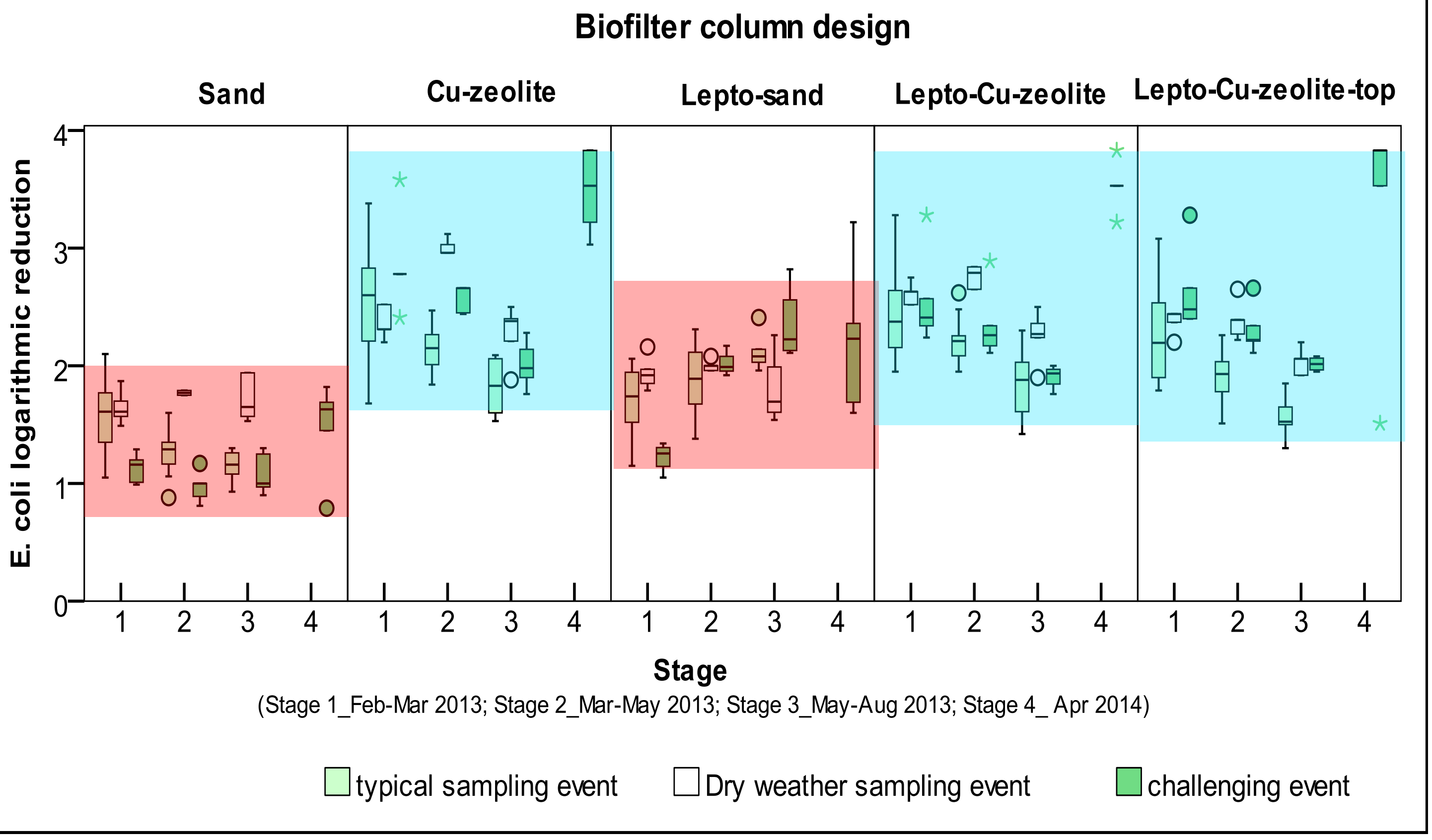


Vegetation

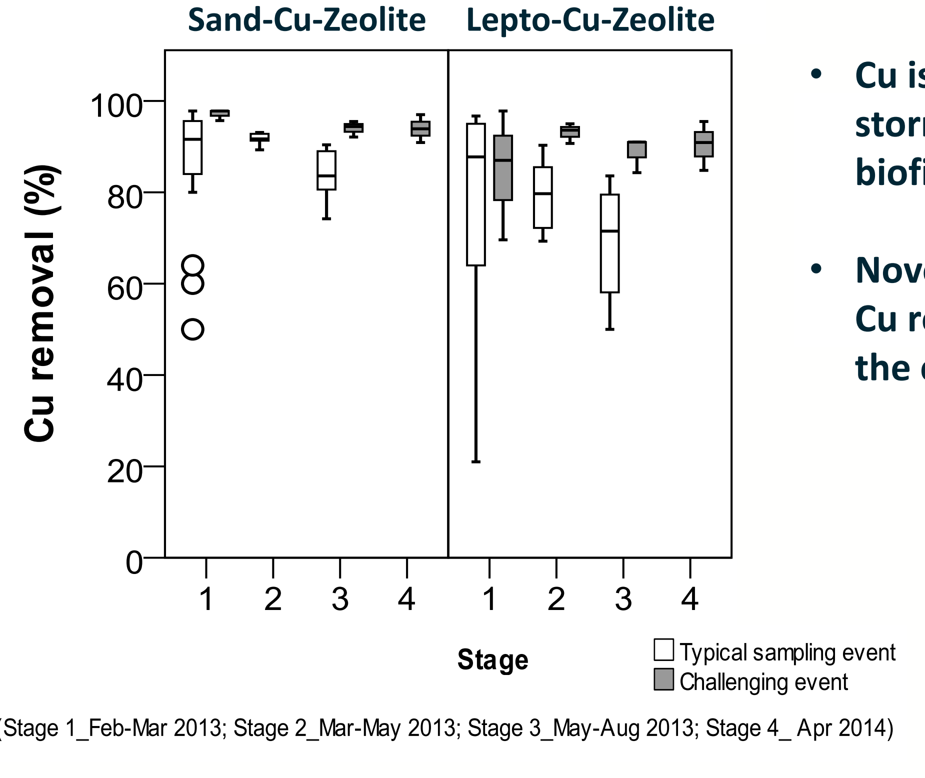
- Soil only
- *Leptospermum Continentale*
- *Soft leaf buffalo*

- *Leptospermum Continentale*

E. coli Removal

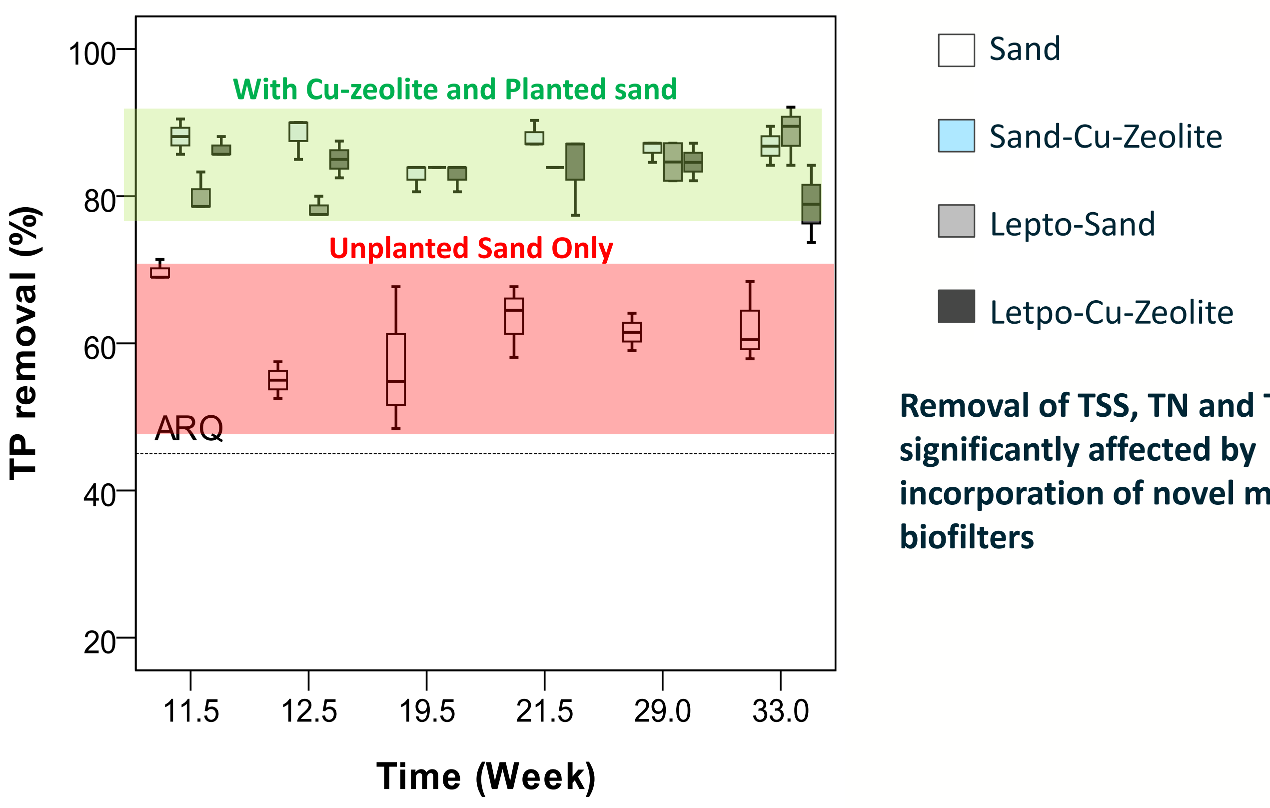


Copper Removal or Leaching ?



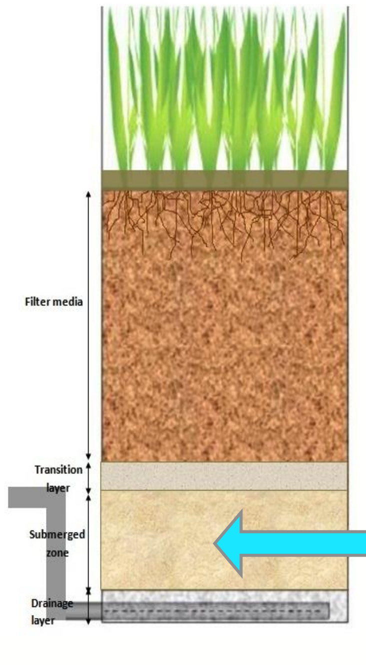
- **Cu is removed from stormwater by novel biofilters**
- **Novel biofilters have similar Cu removal efficiently as the current biofilters**

Removal of Other Pollutants



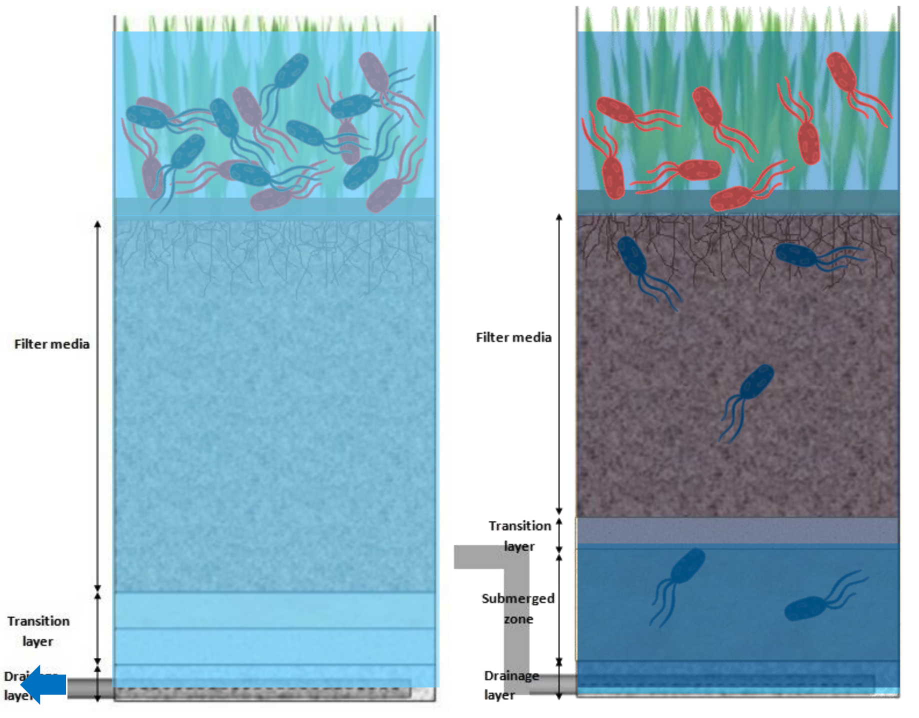
Removal of TSS, TN and TP is not significantly affected by incorporation of novel media in biofilters

Design Characteristics: (3) Submerged Zone



Saturated Zone is important for passive watering of plants and removal of pollutants

Summary: processes that impact microbial removal



Within event (wet weather) processes

- Attachment / straining
- Detachment

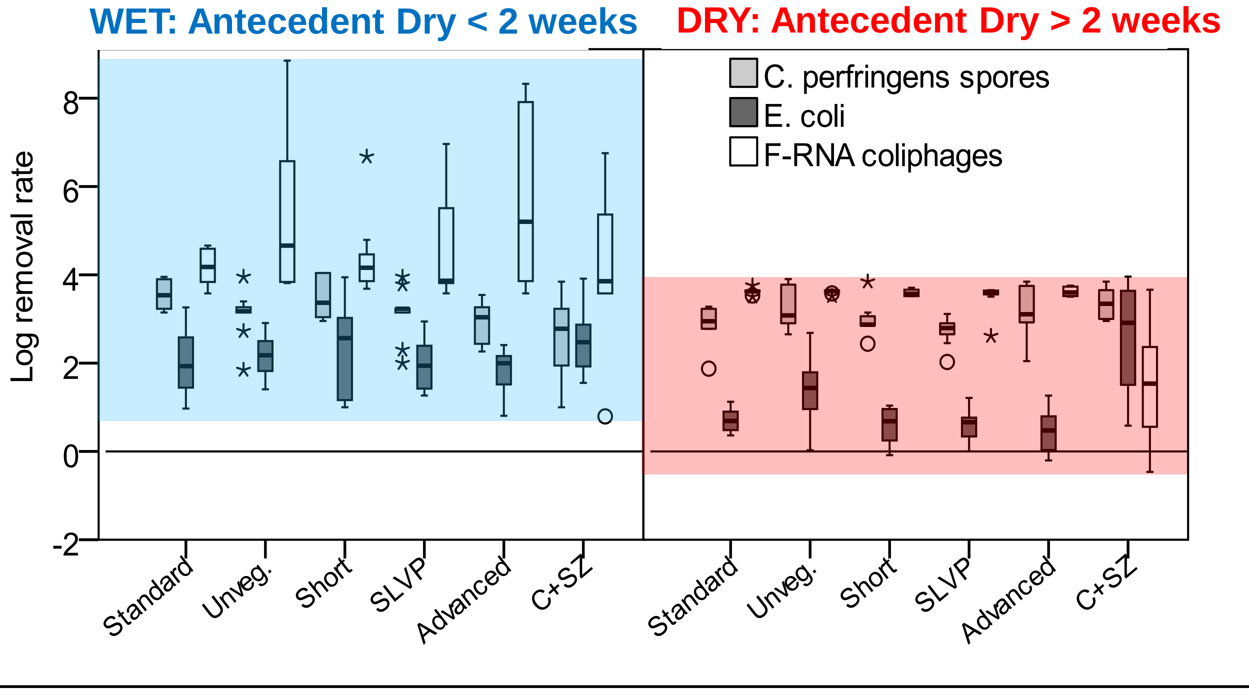
Between event (dry weather) Processes

- Die-off

With SZ Outflow

- Old water/New water

Summary: Effects of Operations on Different Pathogenic Indicators



Proposed Design for Stormwater Harvesting

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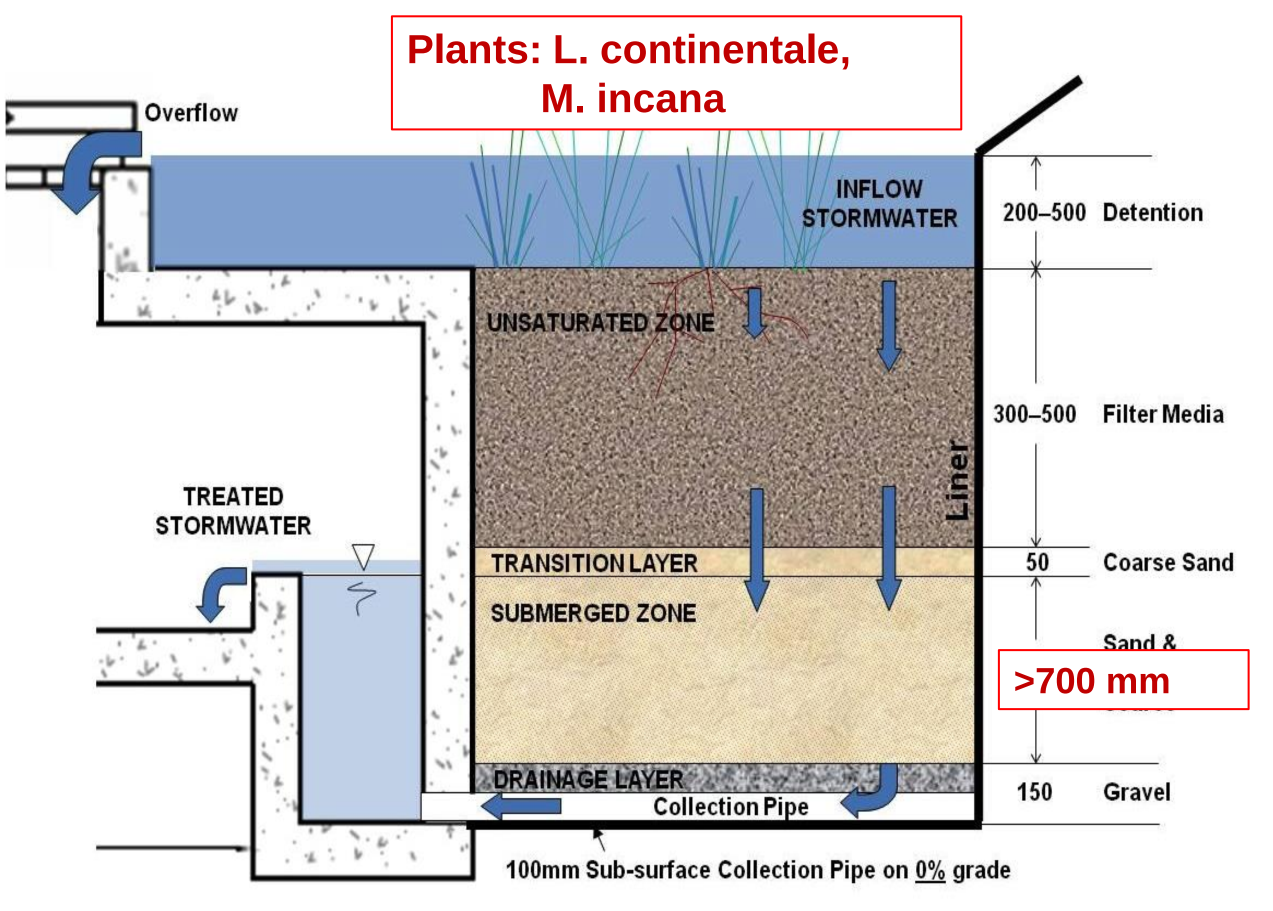
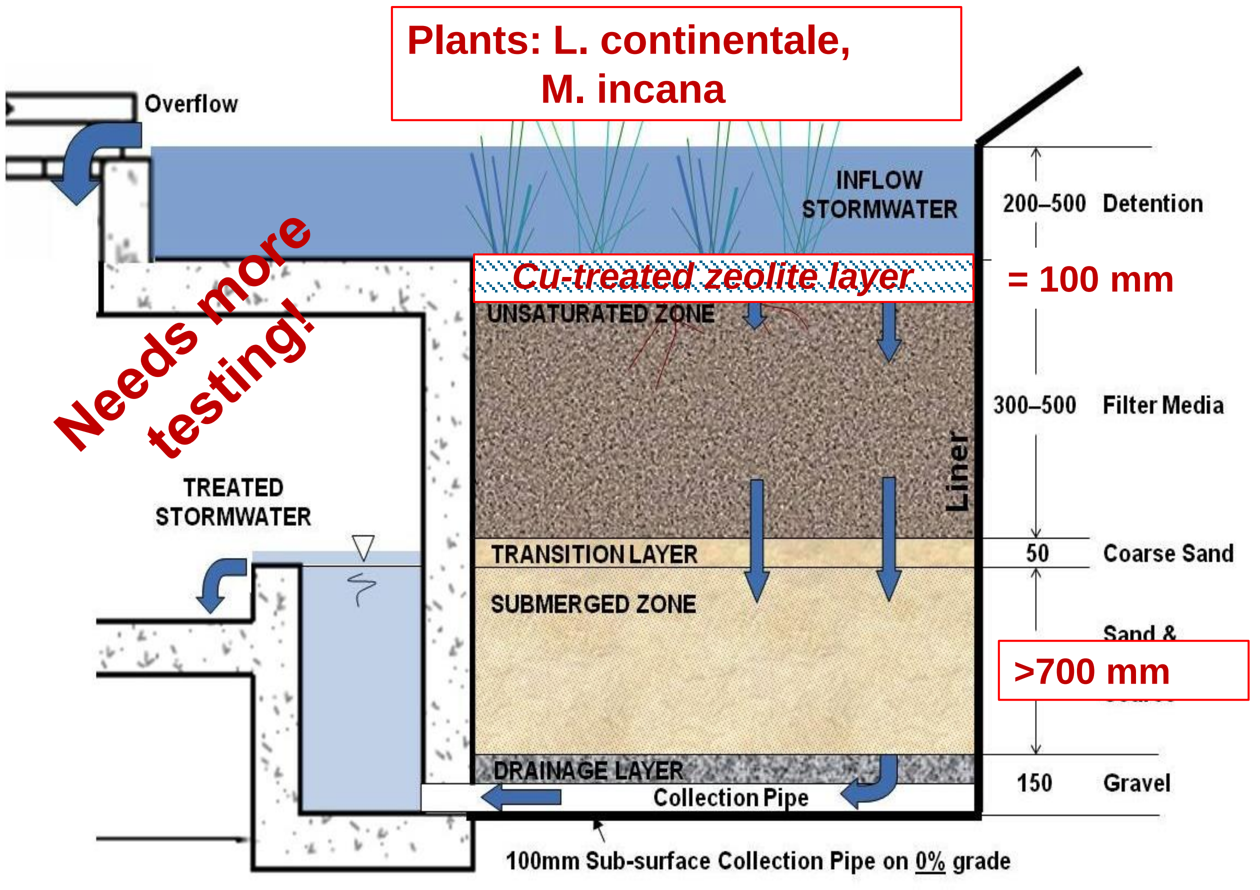
Biofilters for stormwater harvesting



Biofilters for stormwater harvesting



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One more thing,...

Validation for non-potable end use may be required

Aims and Objectives

- ✓ *The system can produce water of the required quality*
- ✓ *The water quality objectives are being continuously met*
- ✓ *Applicable to a wide range of SW systems and sizes*

(1) Pre-Validation

(2) Validation Monitoring

(2) Operational Monitoring

Summary

- Selection of vegetation species with an extensive root system (such as **L. continentale, M. incana**) and maintaining a steady SZ volume are important for faecal microorganism removal in current stormwater biofilters.
- Faecal microbial removal performance in current stormwater biofilters is reduced following both extremely short and extended dry weather periods

Design deep submerged zone!

Summary

- Inclusion of novel Cu-Zeolites can increase pathogen removal >2 log reduction of common indicator microorganisms without compromising the removal of other pollutants (e.g. TSS, TN, TP and Cu).
- This novel biofilters are capable of reducing reference pathogen concentrations, with particularly high removal of protozoa (> 3 log) and greater than 1 log reduction of reference bacterial and viruses
- Performance of the novel biofilters is less affected by intermittent drying/wetting conditions and the size of storm events, but may be reduced during cold temperatures.

Needs further testing!

Treatment Performance

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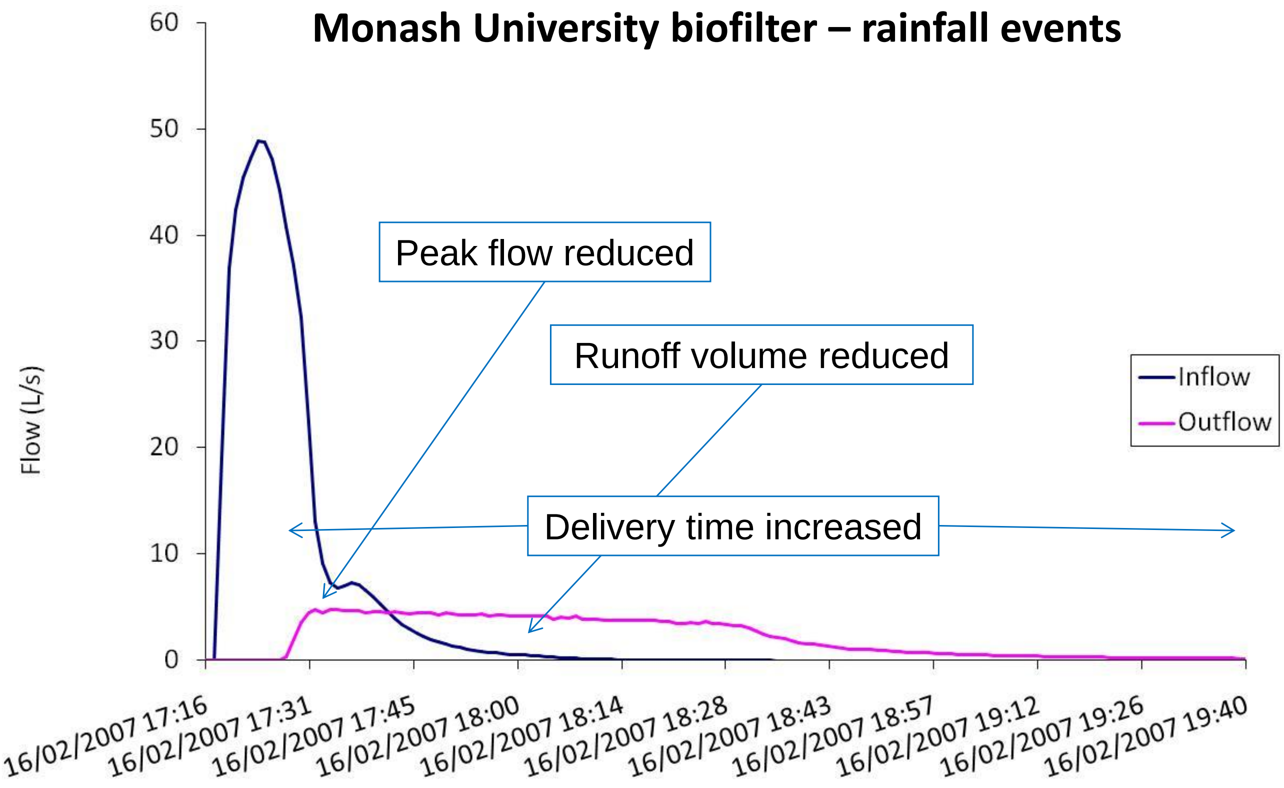
Monitoring in field conditions

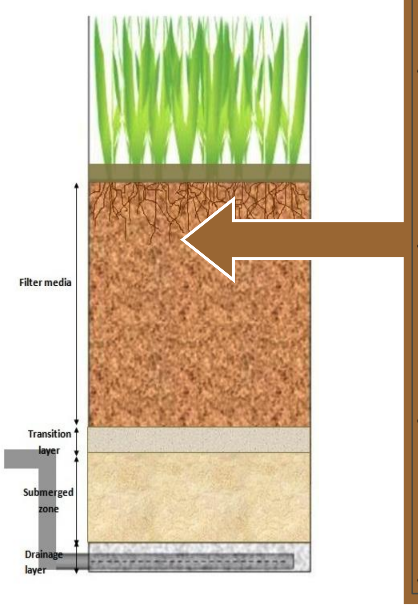
- ***Monash Car Park, Melbourne*** – Rainfall events and challenge tests
- ***Biofilter at Royal Melbourne Golf Club (old residential land-use), Melbourne*** – Rainfall events
- ***Kfar Sava, Israel*** – Rainfall events

Flow Reductions



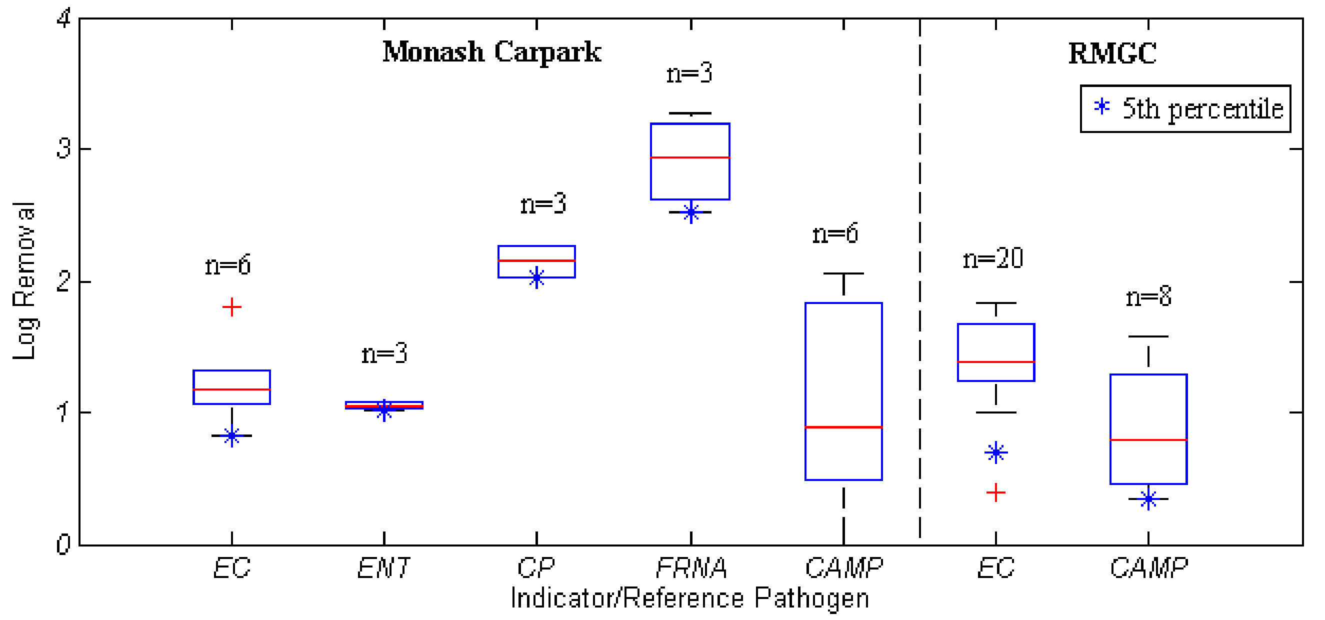
Common pollutants: TSS, TN and TP

Monash University biofilter – Challenge tests



	Test	Cell1 (**Loamy sand, without SZ**)			Cell2 (**Sand, with SZ**)		
		Old/ New ratio	EMC_{CELL1} (mg/L)	Removal (%)	Old/ New ratio	EMC_{CELL2} (mg/L)	Removal (%)
TSS	1st		<1.924	99	2.08	1.499	99
	2nd	1.80	1.644	98	0.83	1.160	98
	3rd	0.50	0.925	98	0.50	1.260	98
TP	1st	0.56	0.152	89	0.29	0.117	92
	2nd	0.61	0.172	89	0.62	0.120	93
	3rd	0.57	0.215	86	0.44	0.160	89
TN	1st	0.84	4.323	-3	0.48	2.201	48
	2nd	1.18	3.984	0.4		N/A	
	3rd	0.77	2.125	34	0.42	1.678	48

Pathogen Removal



EC: E. coli; ENT: Enterococci; CP: Clostridium perfringens; FRNA: FRNA coliphage; CAMP: Campylobacter

Micopollutant Removal

Monash University biofilter – Challenge tests

Micro-pollutant		ADWG [µg/L]	Mean inflow [µg/L]	Outflow EMC [µg/L]					
				Cell 1			Cell 2		
				Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Petrol and oils	TPHs	N/A	4300	<100					
	Pyrene	150	9.7	<1					
	Naphthalene	70	17.3	2.0	2.2	2.0	2.7	1.2	3.0
Herbicides	Glyphosate	1000	1600	99	116	187	29	106	70
	Atrazine	20	48.1	**25**	**28**	**27**	**35**	**42**	**49**
	Simazine	30	42.3	22	**32**	24	**33**	**49**	**43**
	Prometryn	20	46.0	11	14	15	**20**	**29**	**32**
Plastic and polymer production	DBP	35	42.2	<3					
	DEHP	10	17.0	<5					
	Chloroform	200	59.0	32	38	40	40	47	49
Disinfectants	**PCP**	10	27.1	0.7	6.0	4.3	2.1	**18.7**	**11.1**
	Phenol	N/A	203.3	2.2	1.0	47.5	0.9	2.8	106.4

Good!

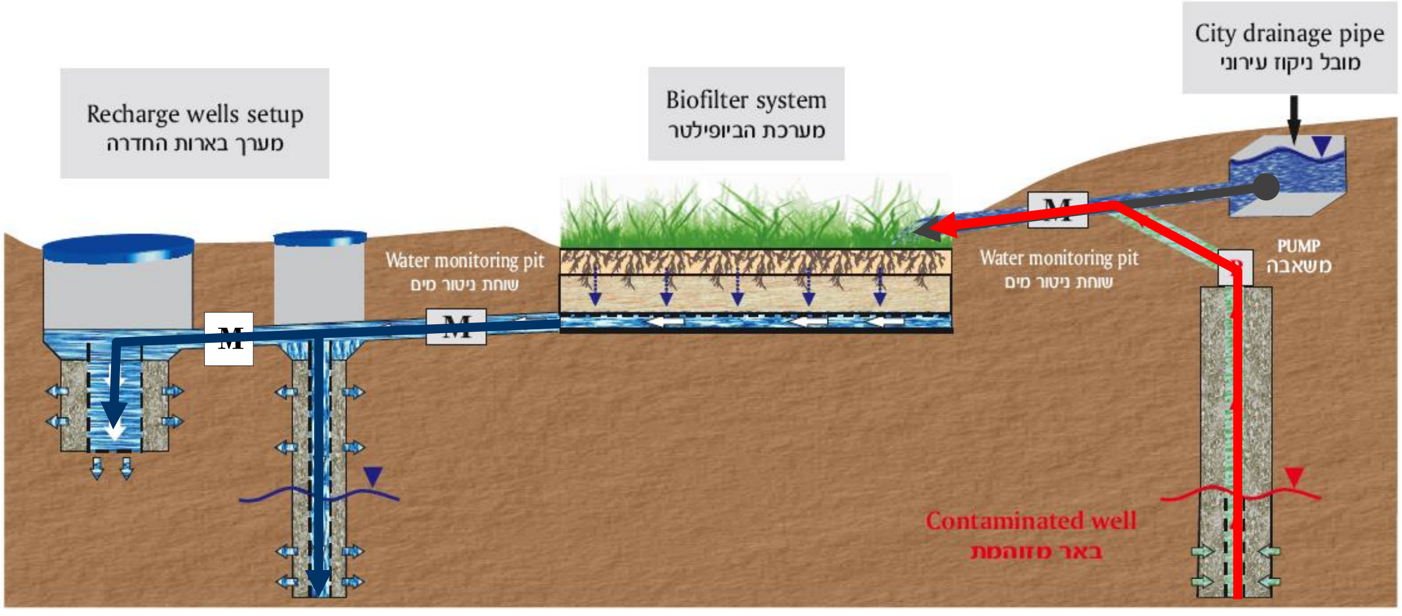
No Good!

Good!

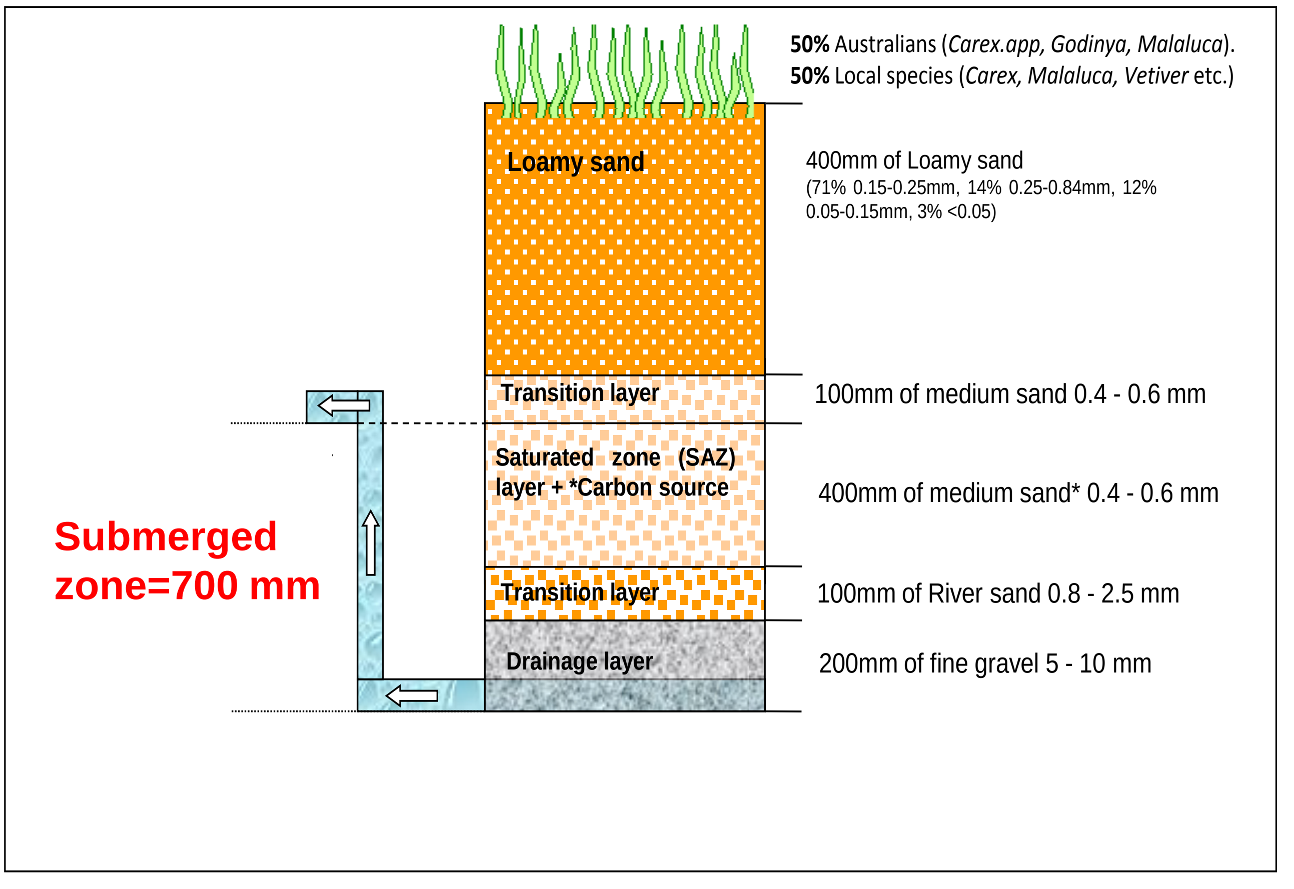
No Good!

Kfar-Sava (Israel) biofilter for groundwater recharging

Principle of operation



Cross-section of Kfar Sava Biofilter



Plants of Kfar Sava Biofilter

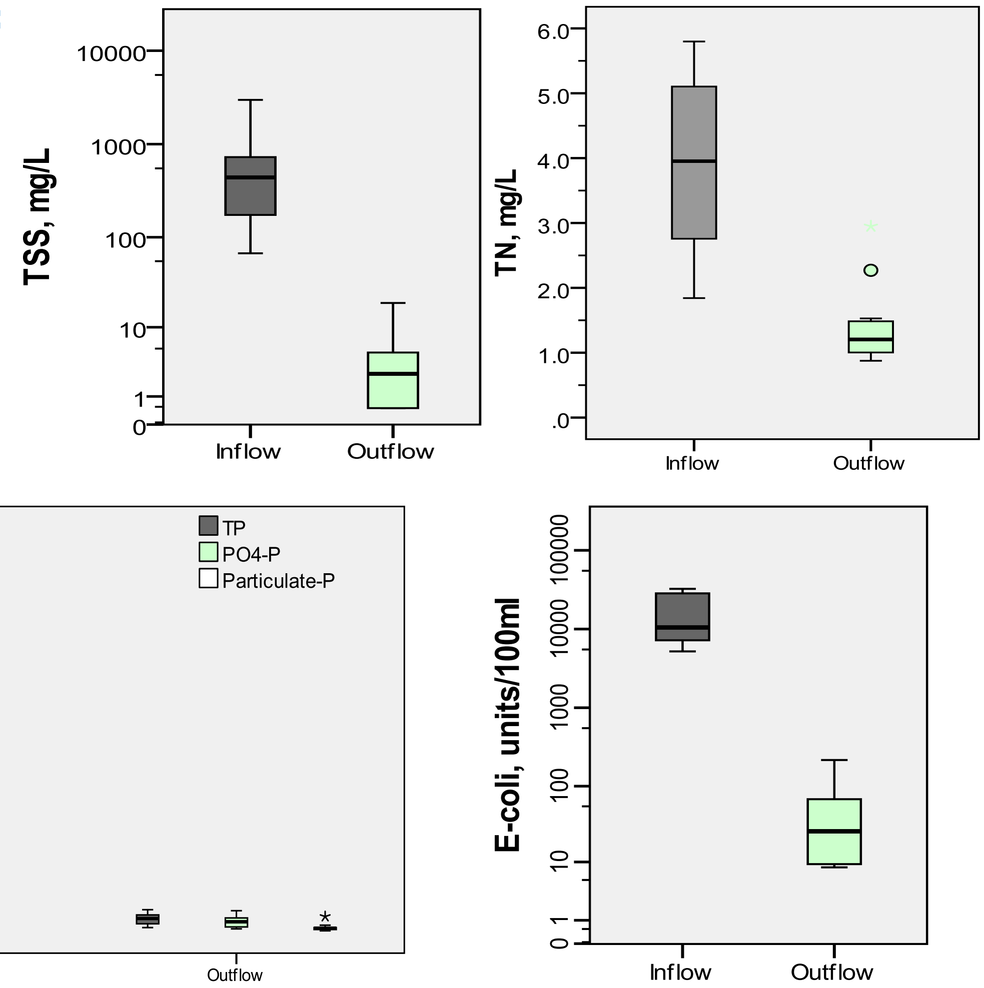
Carex appressa | *Carex glauca* | *Goodenia ovata* | *Melaleuca linariifolia*

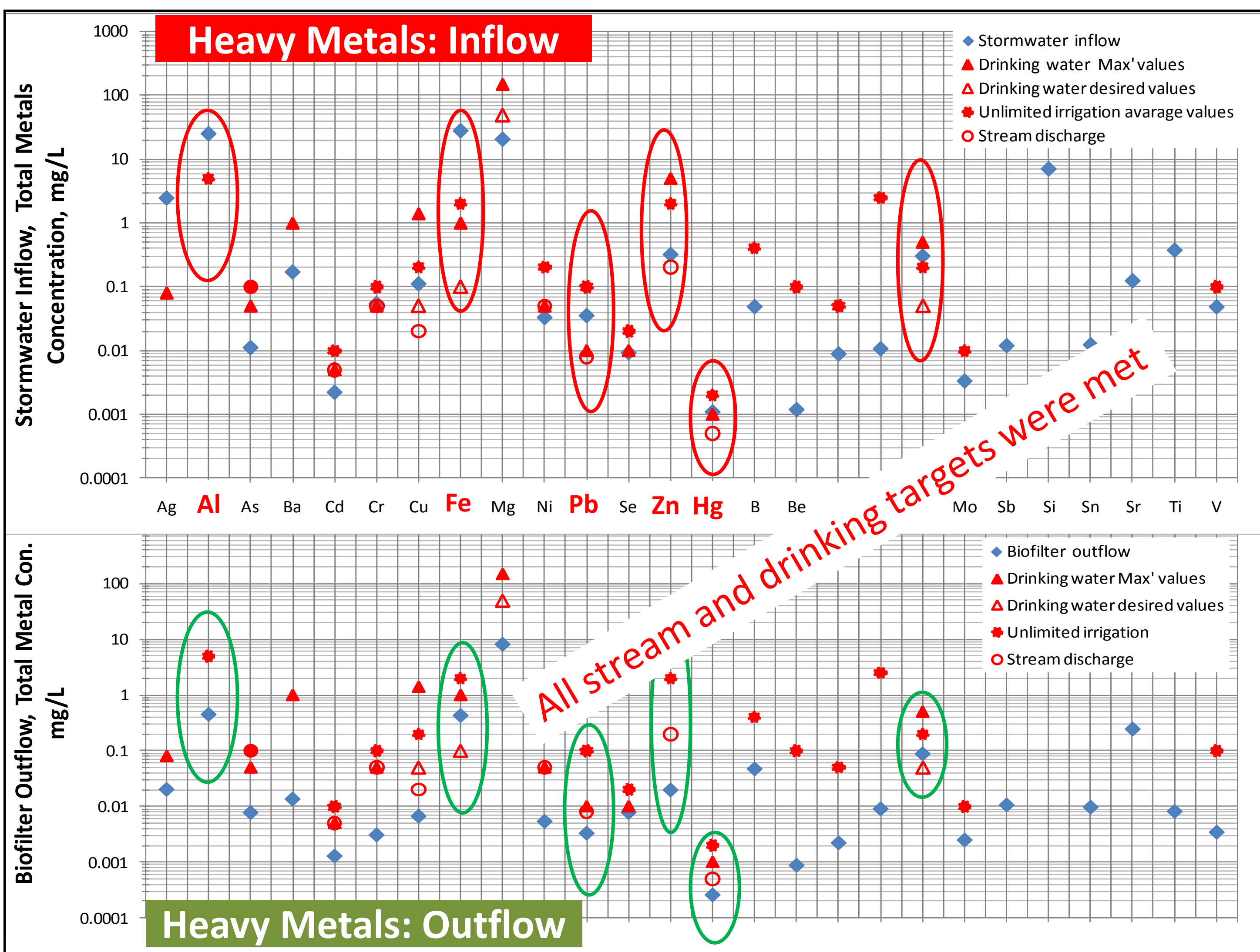
Melaleuca green doom | *Melaleuca ericifolia* | *Juncus effuses 'spiralis'* | *Zantedescia ethiopica*

Vetiver | *Agapantos* | *Tulbergia* | *Louisiana irises*

Monitoring of 16 EMCs

(Event Mean Concentrations)





What performance can we expect from a well designed biofilter?

Reductions in concentrations of ‘typical’ stormwater:

- Over **95%** of Total Suspended Solids,
- Over **50%** of Total Nitrogen (TN)
- Over **65%** of Total Phosphorous (TP),
- Over **90%** of heavy metals
- Over **99%** of hydrocarbons (never detected)
- Over **1 log reduction** of key pathogen indicators and some pathogens

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Questions?

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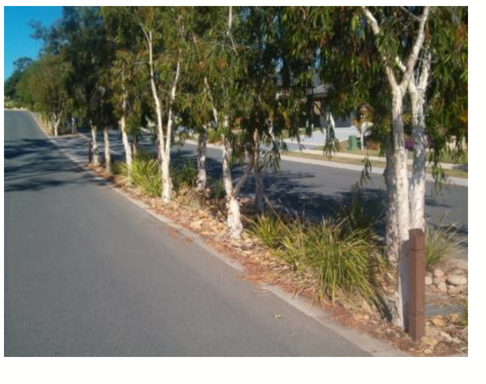
Long-term Operation

Australian Government
Department of Industry and Science
Business
Cooperative Research
Centres Programme

Key Issues

- Extensive research undertaken on biofilter performance

  BUT
- Monitoring largely restricted to short-term studies on new(ish) systems
- Remaining questions regarding long-term operation
  - Clogging
  - Plant uptake capacity
  - Accumulation of toxicants



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Clogging

- Blocking of pore spaces in filter media with fine sediment carried in with stormwater
- 43% of tested systems were below guidelines for hydraulic conductivity (<50 mm/hr)
  - Survey of 40 systems conducted in 2007
- Why is it a problem?
  - ↑ untreated overflows
  - Impacts on plant health/survival

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Clogging

- Possible causes:
  - Inappropriate filter media
  - Inadequate sediment control (i.e. clogging)
- Solutions:
  - Plants
  - Alternate inundation & drying
  - Better design?

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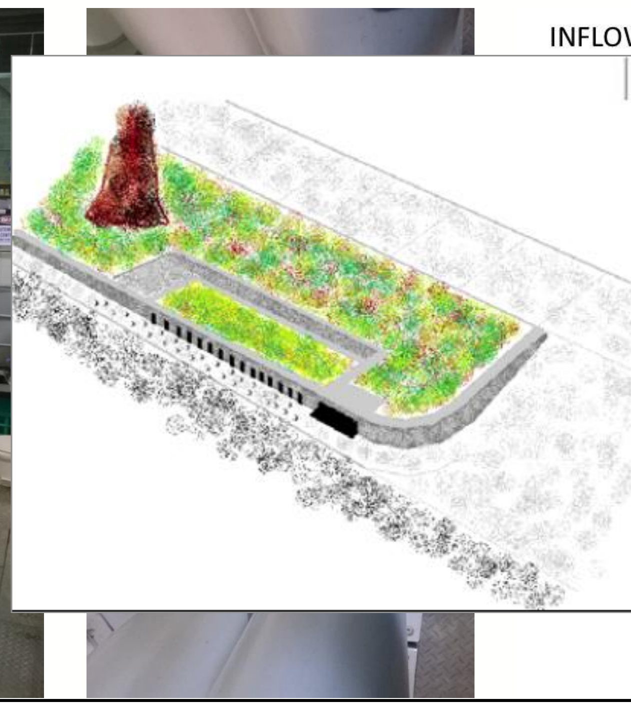
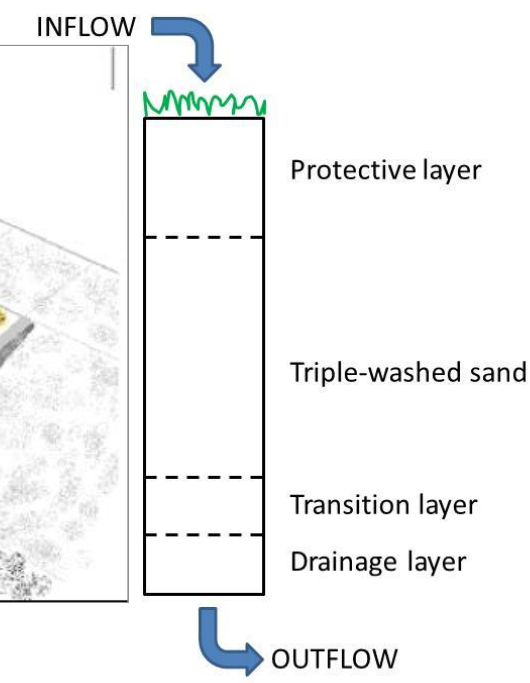
Clogging

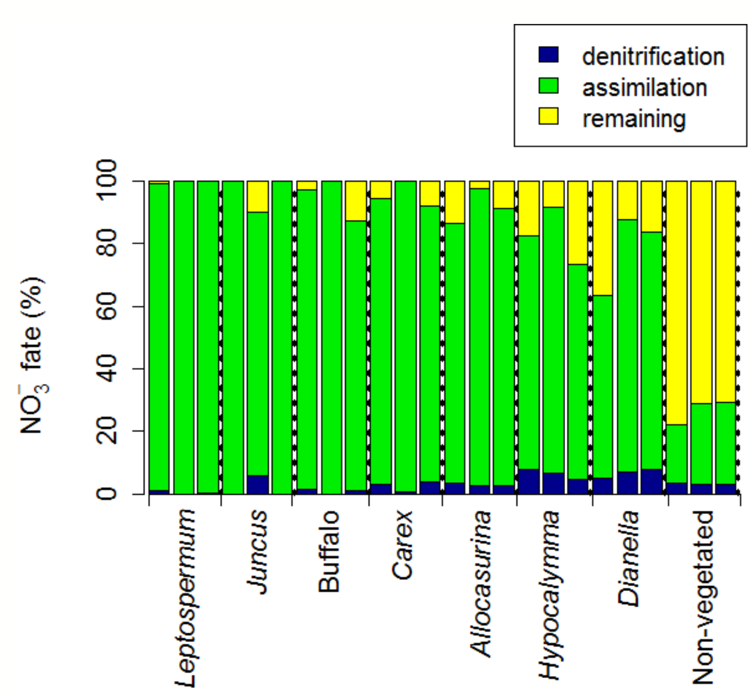
- Alternative filter media arrangement
- After the equivalent of 18 months operation, outflow from systems with a protective layer up to 2x higher





Relative importance of nitrogen removal pathways

- Plant assimilation responsible for 89-99% of nitrate uptake (0-8% denitrified)



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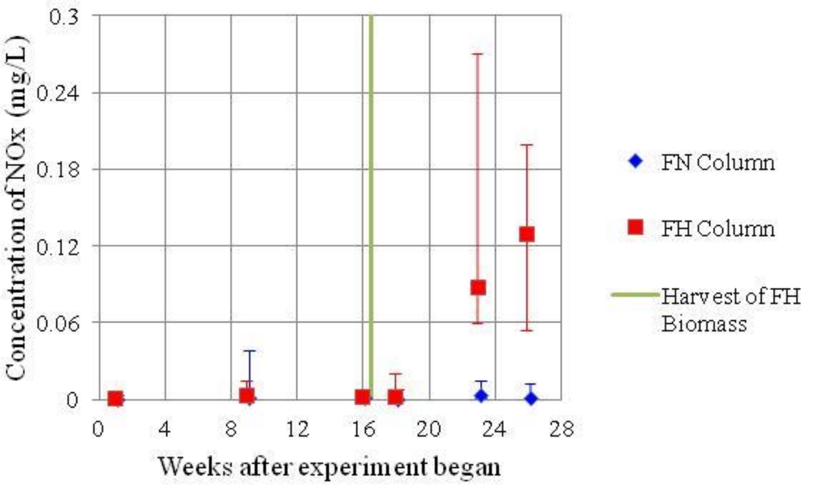
How effective are plants in the long term?

- Will assimilation remain a major nutrient removal pathway across the entire biofilter lifespan?
- Will biofilters reach a point of zero net nutrient retention?
- Does pruning affect nutrient removal?



Performance may decline following pruning
-> depends on plant species

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Accumulation of heavy metals – a cause for concern?

- 2 surveys of 66 field-scale biofilters at 8 sites across Melbourne
  - Survey 1: 2006/7
  - Survey 2: 2014
- Variable
  - Age: 0.5 – 11 years
  - Biofilter size/Catchment area: 0.1 – 29%
  - Land-use: residential, commercial, industrial
  - Urban density: low, medium, high
  - Development: retrofit, renewal

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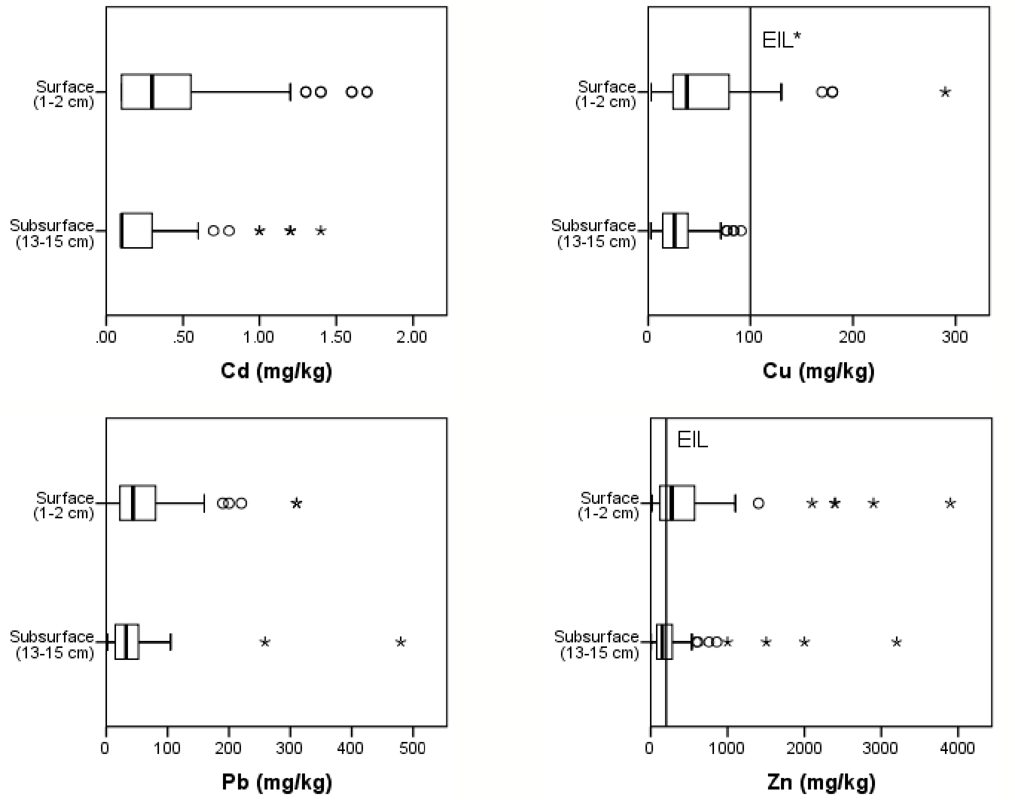
Accumulation of heavy metals – a cause for concern?



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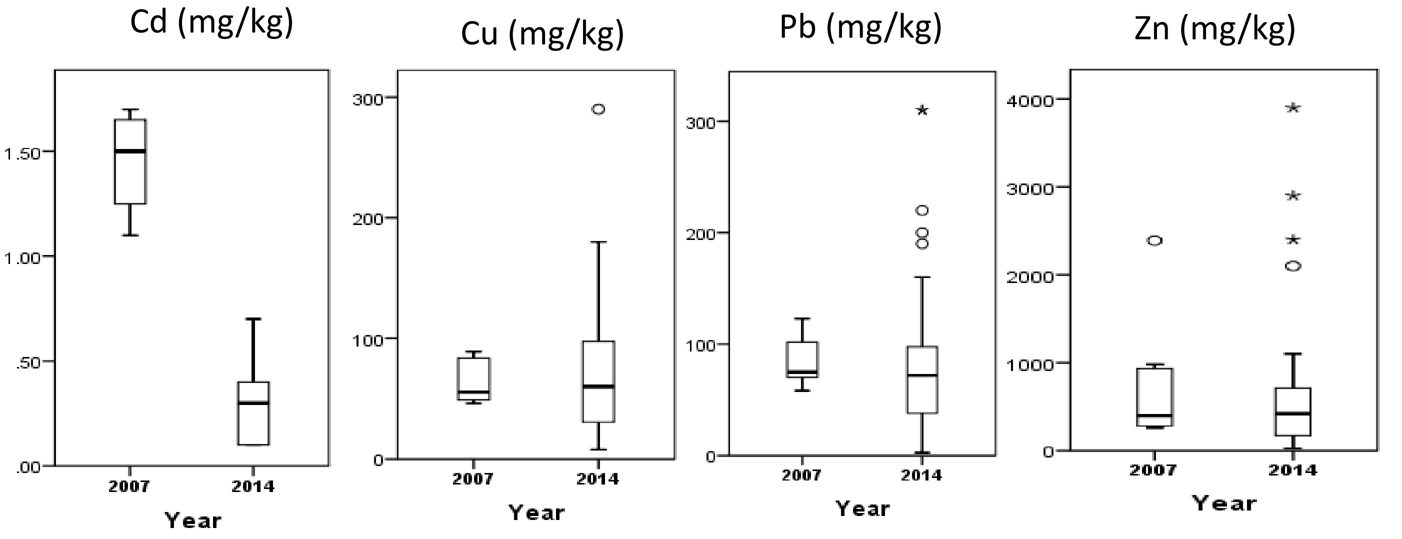
Highlights of the research findings

- Metals accumulation in filter media may not be a problem!



Level of Heavy Metals in Cremorne St. biofilters in 2007 and 2014

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Questions?

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Monitoring & Evaluation

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Why Monitor?

- Demonstrate compliance with legislative requirements or recommended performance targets
  - e.g. “to determine the nitrogen load reduction performance of a biofilter”
- Assess overall and/or long-term performance
- Collect data for model development
- Understand detailed processes
- Improving future design & implementation

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Types of Monitoring

- Qualitative
- Quantitative
  - Flow
  - Water Quality

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Qualitative Monitoring

Parameter	Indicator of	Possible Cause(s)
Plant health	Too much water	Undersizing Water logging
	Too little water	Oversizing Inlet/outlet level wrong
	Poor flow control	High inflow velocities Inadequate high flow bypass
Filter media – Evenness of surface	Poor flow control (erosion)	High inflow velocities Inadequate high flow bypass
	Compaction (tyre marks, trail, plant loss)	Vehicle/pedestrian damage
Sediment build-up	Clogging	High sediment loads Undersizing Inadequate pre-treatment

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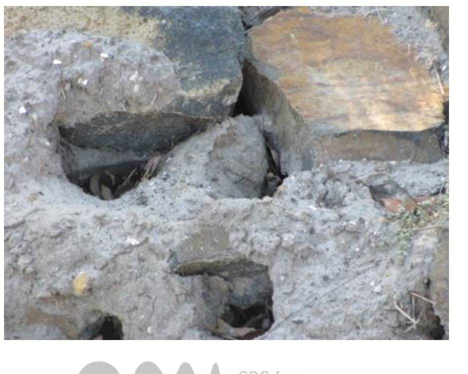
Qualitative Monitoring

- What to look for:





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