Performance

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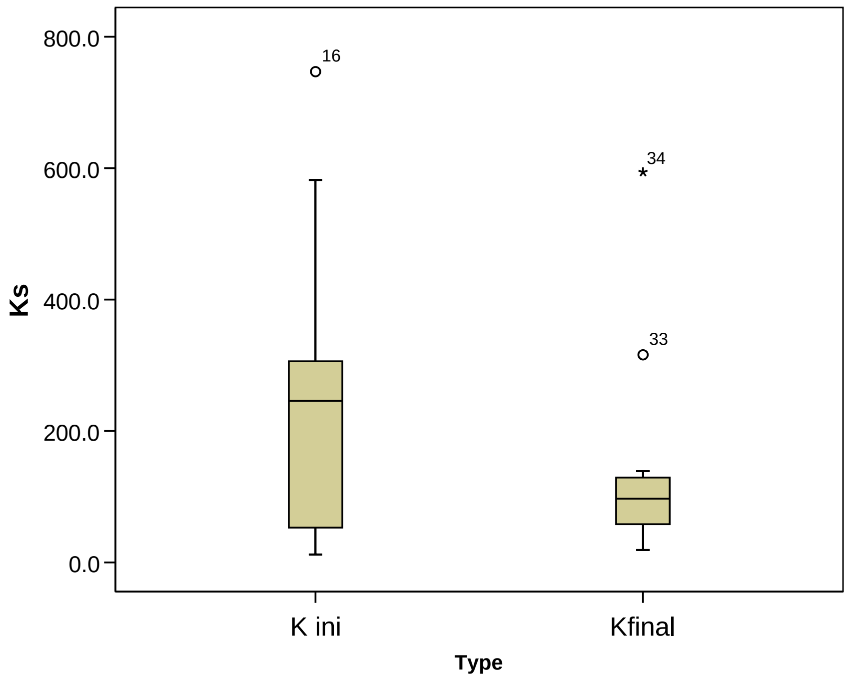
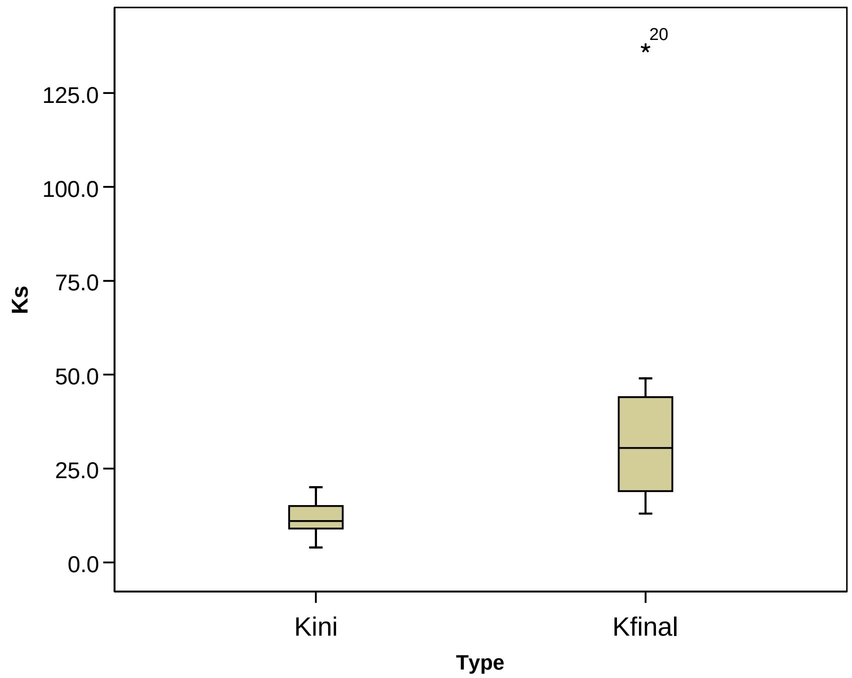
FAWB
Facility for Advancing Water Biofiltration

MONASH University

Hydraulic Performance

What governs hydraulic performance?

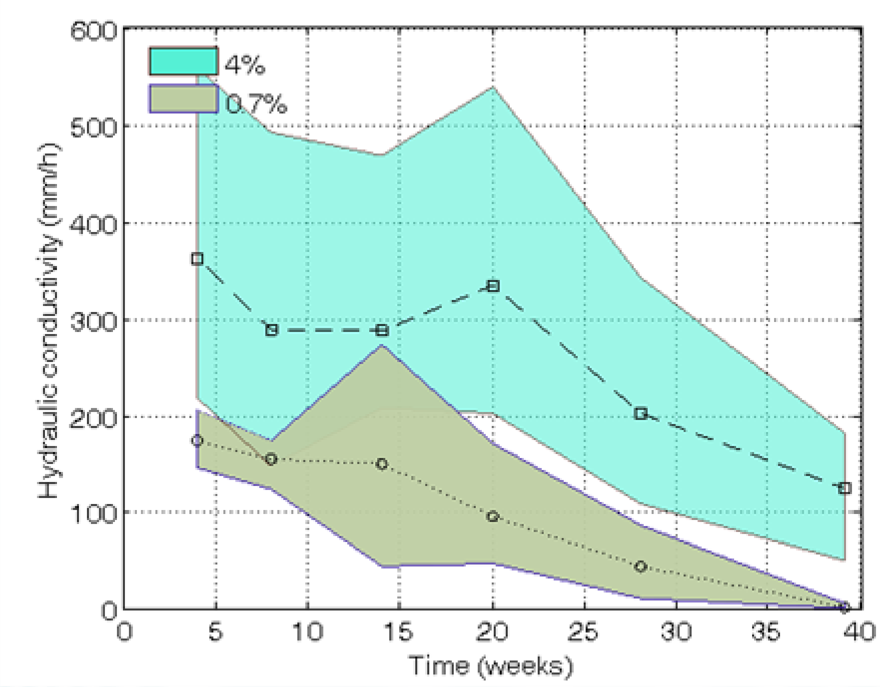


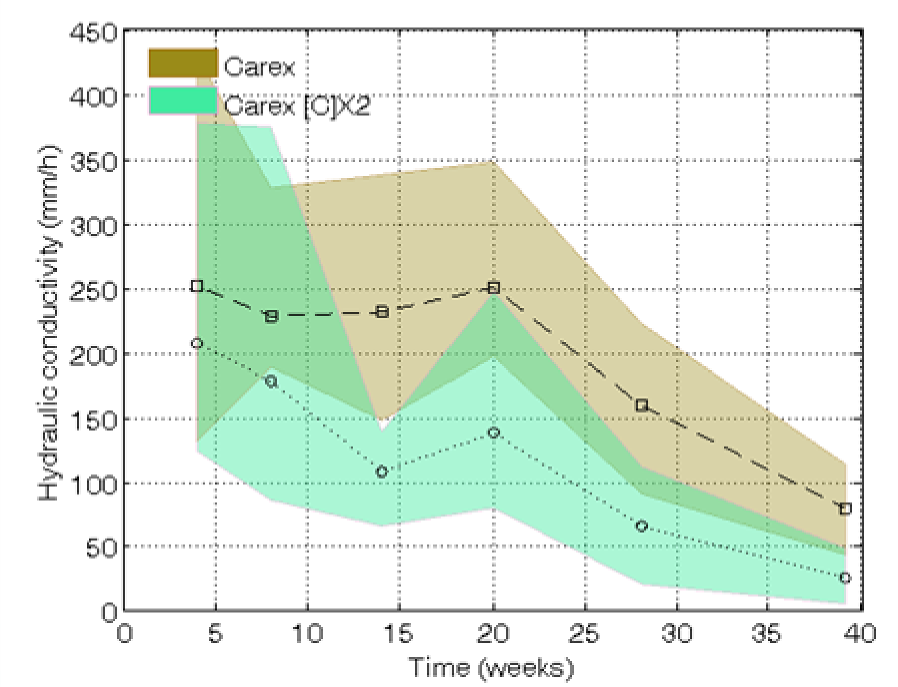


Initial K_s should be >100 mm/hr to ensure an adequate long-term infiltration capacity

Le Coustumer, S., T. D. Fletcher, A. Deletic, S. Barraud and J. Lewis (under review). Hydraulic performance of biofilter systems for stormwater management: lessons from a field study. *Journal of Hydrology.*

What governs hydraulic performance?





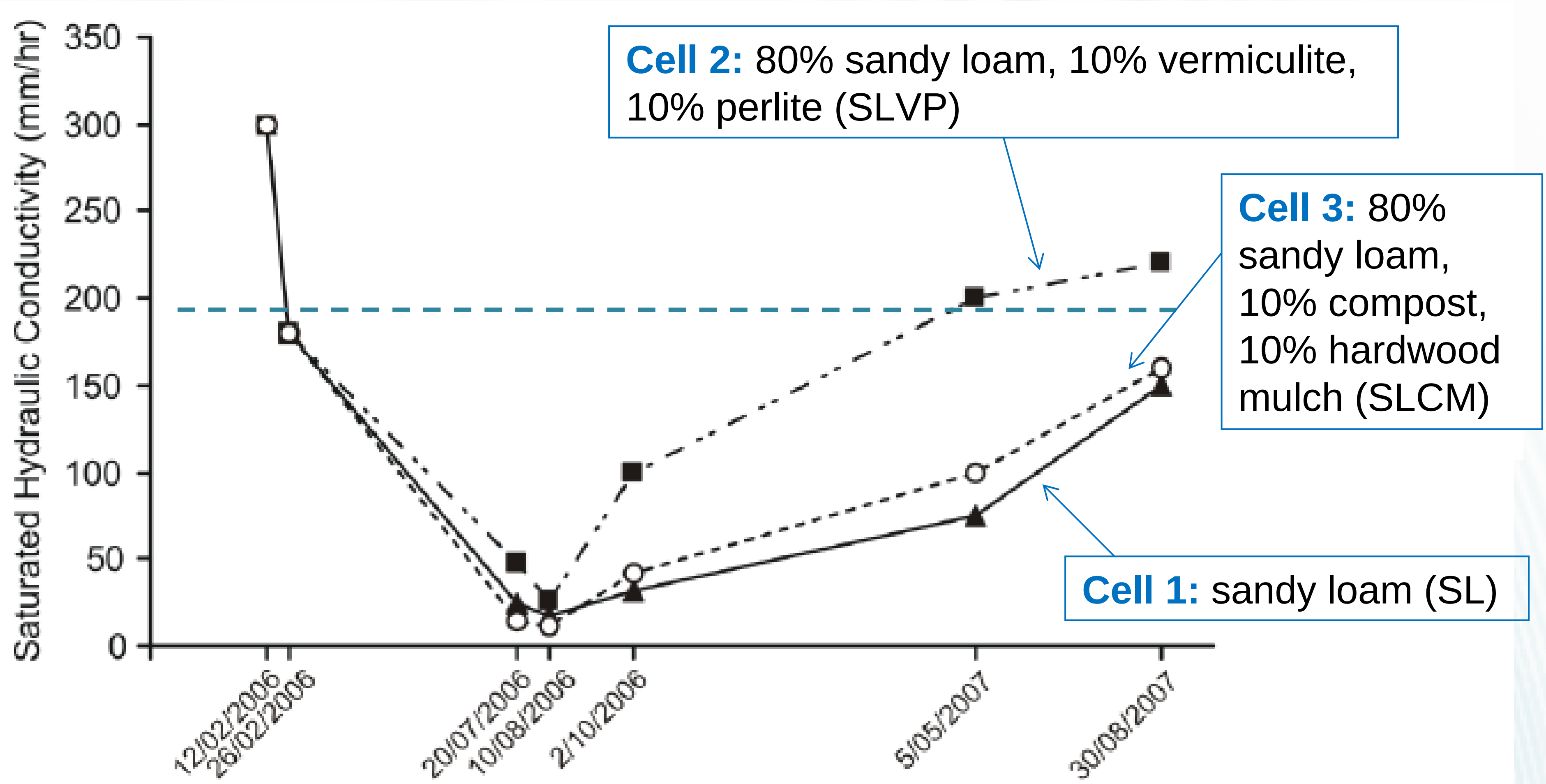
Surface clogging may be a problem for systems that are under-sized or service catchments with high silt loads

Le Coustumer, S., P. Poelsma, T. D. Fletcher, A. Deletic and S. Barraud (under review). Clogging and metal removal by stormwater biofilters: a large-scale design optimisation study. *Journal of Hydrology.*

Does hydraulic performance change with time?

- Biofilters will experience a sharp drop in hydraulic conductivity immediately following construction
  - Mainly due to compaction
- Infiltration capacity will recover due to plant activity
  - Provided the system is not overloaded by silt

Does hydraulic performance change with time?



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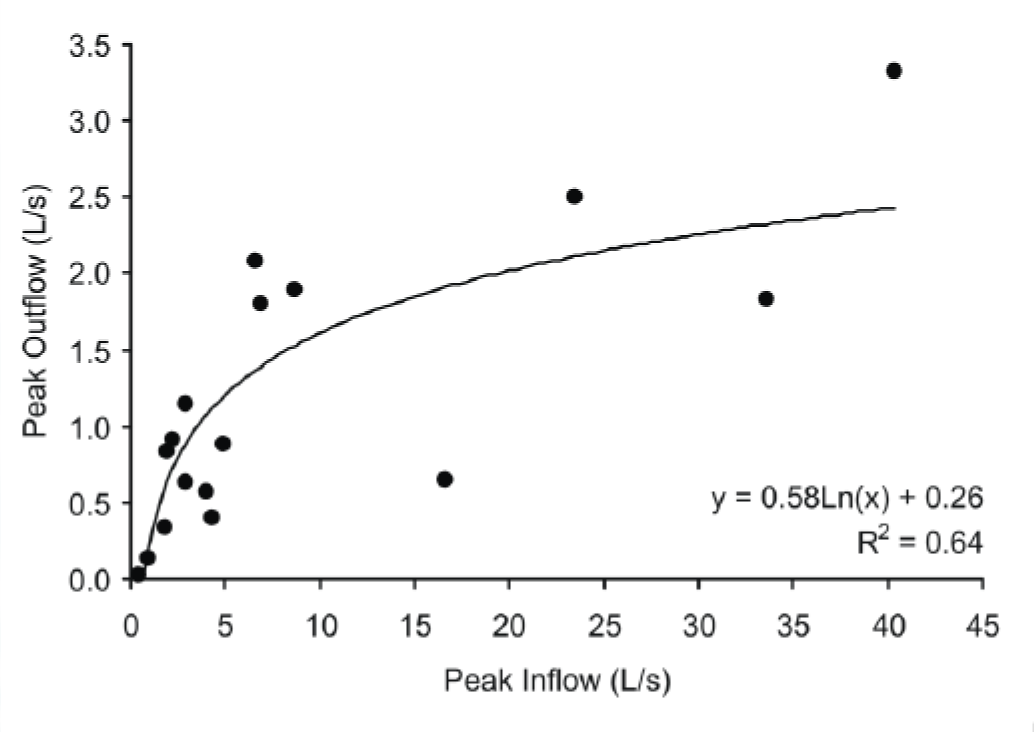
Hydraulic Performance

- Other Considerations:
  - Not all vegetation is useful for maintaining infiltration capacity
    - Large diameter roots better than fine roots

Flow Reductions

- Can expect significant reductions in peak flows
  - On average, peak flows were reduced by 80% at the Monash University biofilter
  - Similar findings at the Saturn Cres biofilter



Hatt, B. E., T. D. Fletcher and A. Deletic (in press). Hydrologic and pollutant removal performance of stormwater biofiltration systems at the field scale. *Journal of Hydrology.*

Flow Reductions

- Can expect significant reductions in runoff volumes due to evapotranspiration

Results from the Saturn Cres storm simulations:

- Lined system
- Variation in losses explained by soil moisture content

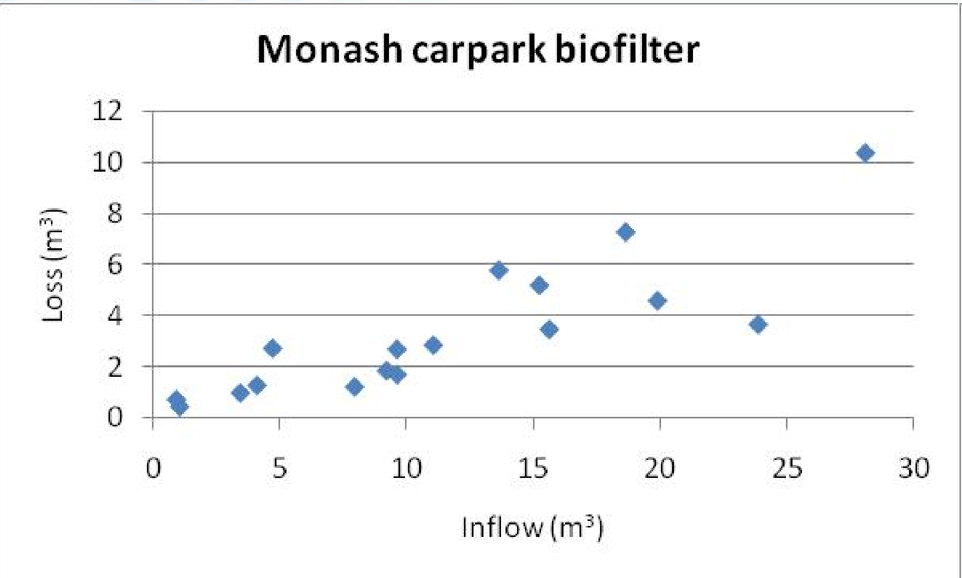
Simulation	Inflow (L)	Outflow (L)	Loss (L)	ADWP (days)	Peak Q_{out}	
					(L/s)	(as a % of mean Q_{in})
25 October 2006	3000	2593	407 (14%)	3	0.48	14
19 June 2007	3000	2097	903 (30%)	11	0.48	14
23 October 2007	3000	2226	774 (26%)	12	0.66	20
24 October 2007	3000	2670	330 (11%)	0	0.50	15

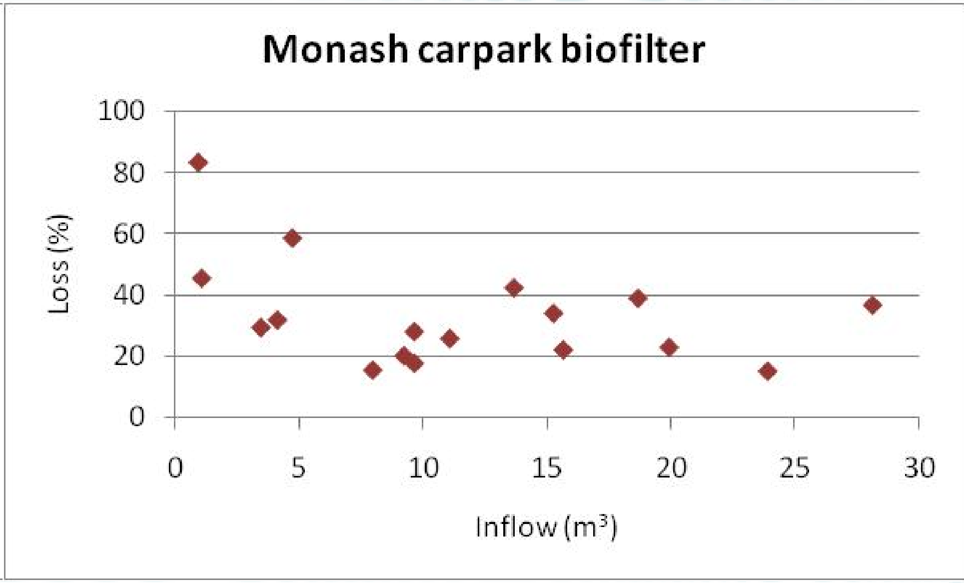
Hatt, B. E., T. D. Fletcher and A. Deletic (in press). Hydrologic and pollutant removal performance of stormwater biofiltration systems at the field scale. *Journal of Hydrology.*

Flow Reductions

Results from the Monash carpark biofilter:

- On average, runoff volumes reduced by 33%
- Small to medium storms
- System lined and undersized





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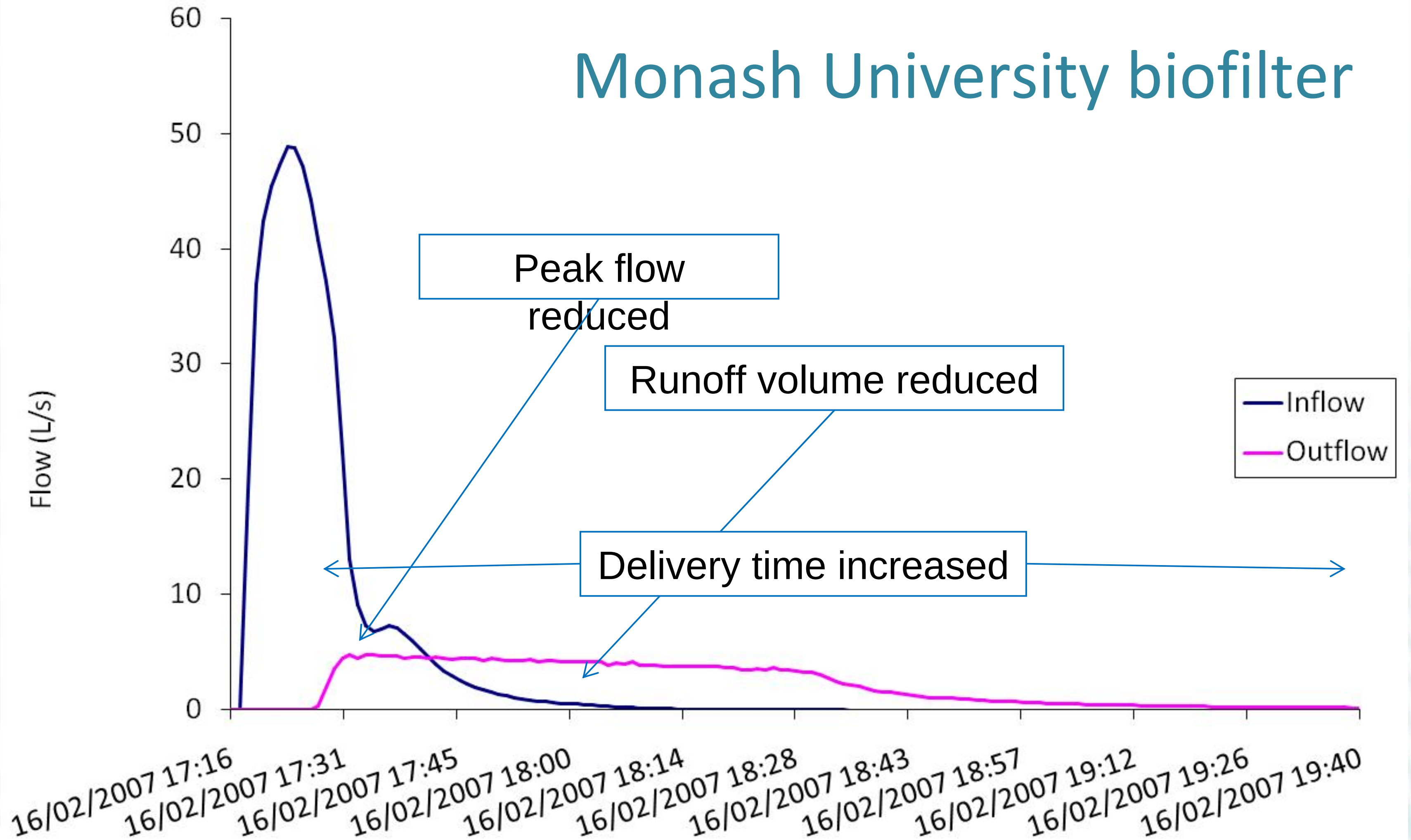
Flow Reductions



Flow Reductions

- Other Considerations:
  - Systems should be built to promote exfiltration wherever possible

Biofiltration systems can contribute significantly to restoring catchment hydrology to its pre-development state and so protect the health of urban waterways

Treatment Performance

What is the optimal treatment performance?

If designed properly, vegetated, soil-based biofilters will remove:

- >95% of TSS
- >90% of heavy metals
- >85% of TP
- >50% of TN
  - And >70% for some design configurations
- Good for pathogens

What is the optimal treatment performance?

If designed poorly, biofilters will remove:

- High levels of TSS
- High levels of heavy metals

BUT they will:

- Leach phosphorus
- Leach nitrogen
  - Where outflow concentrations may be more than twice the inflow concentrations

Examples of poor design:

- Non-vegetated or inappropriately vegetated
- Use of filter media with high levels of organic matter

Some results...

Any filter media type will effectively remove TSS and metals....

TABLE 2. Pollutant Removal Summary for Six Filter Media Types

	TSS	TP	TN	TOC	Cu	Mn	Pb	Zn
Event mean hydraulic loading (g/m^2)								
	29	0.08	0.45	1	0.06	0.01	0.15	0.22
Load Reduction (%)								
S	99 ± 1	97 ± 1	38 ± 1	59 ± 8	97 ± 1	94 ± 1	99 ± 1	99 ± 1
SL	93 ± 4	−65 ± 16	−18 ± 15	−103 ± 17	97 ± 1	−32 ± 54	99 ± 1	99 ± 1
SLH	92 ± 3	−143 ± 17	−37 ± 4	−146 ± 19	96 ± 1	−71 ± 19	99 ± 1	98 ± 1
SLVP	90 ± 3	−73 ± 15	−23 ± 12	−129 ± 22	94 ± 2	−26 ± 52	95 ± 2	96 ± 4
SLCM	92 ± 4	−409 ± 40	−111 ± 41	−178 ± 13	94 ± 1	−152 ± 100	97 ± 1	96 ± 1
SLCMCH	96 ± 1	−437 ± 50	−164 ± 14	−165 ± 5	93 ± 1	−178 ± 189	97 ± 1	96 ± 1

Load reductions are reported as the mean of three replicates ± standard deviation. Note: a negative load reduction indicates leaching of previously retained pollutants and/or native material.

... but non-vegetated and/or the wrong type of filter media will result in nutrient leaching

Hatt, B. E., T. D. Fletcher and A. Deletic (2008). Hydraulic and pollutant removal performance of fine media stormwater filtration systems. *Environmental Science & Technology* ***42(7): 2535-***

Some results...

If we get the filter media right, phosphorus will effectively removed...

Factors tested	Vegetation	Inflow volume	Filter media depth	Filter media type	Inflow conc.	TP Concentration (mg/L)	TP Removal (%)	PO_4^{3-} Concentration (mg/L)	PO_4^{3-} Removal (%)
Vegetation	None	Std.	700	SL	Std.	0.083 (15)	81 (4)	0.064 (15)	50 (15)
	Carex	Std.	700	SL	Std.	0.023 (22)	95 (1)	0.013 (21)	90 (2)
	Dianella	Std.	700	SL	Std.	0.092 (19)	78 (5)	0.072 (16)	44 (20)
	Microleana	Std.	700	SL	Std.	0.074 (12)	83 (3)	0.050 (22)	61 (14)
	Leucophyta	Std.	700	SL	Std.	0.098 (9)	77 (3)	0.076 (13)	40 (19)
	Melaleuca	Std.	700	SL	Std.	0.070 (17)	84 (3)	0.034 (35)	74 (13)
Volume	Carex	Low	700	SL	Std.	0.024 (48)	94 (3)	0.013 (45)	90 (5)
	Carex	High	700	SL	Std.	0.046 (12)	89 (1)	0.027 (28)	79 (8)
	Microleana	High	700	SL	Std.	0.104 (9)	76 (3)	0.087 (8)	32 (17)
	Melaleuca	High	700	SL	Std.	0.078 (29)	82 (7)	0.045 (39)	64 (22)
			500	SL	Std.	0.032 (26)	93 (2)	0.016 (24)	87 (4)
			300	SL	Std.	0.038 (22)	91 (2)	0.022 (18)	83 (4)
			500	SL	Std.	0.078 (14)	82 (3)	0.062 (17)	52 (16)
			300	SL	Std.	0.078 (6)	82 (1)	0.053 (6)	58 (4)
			500	SL	Std.	0.060 (39)	86 (6)	0.033 (60)	74 (21)
	Melaleuca	Std.	300	SL	Std.	0.050 (40)	88 (5)	0.024 (79)	81 (18)
Filter media type	Carex	Std.	700	SLVP	Std.	0.040 (31)	91 (3)	0.021 (35)	83 (7)
	Carex	Std.	700	SLCM	Std.	0.264 (48)	38 (78)	0.226 (49)	-78 (>100)
Inflow Conc.	Melaleuca	Std.	700	SL	High	0.068 (24)	91 (2)	0.030 (34)	96 (1)
	Microleana	Std.	700	SL	High	0.064 (14)	91 (1)	0.049 (17)	93 (1)
	Carex	Std.	700	SL	High	0.028 (30)	96 (1)	0.015 (35)	98 (1)
	None	Std.	700	SL	High	0.086 (6)	88 (1)	0.065 (6)	91 (1)

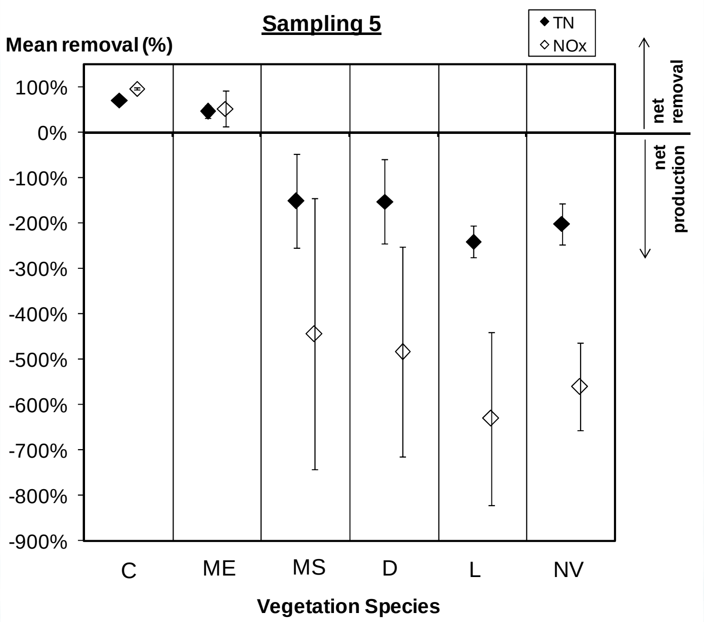
SLCM: sandy loam with 10% compost and 10% mulch

Bratieres, K., T. D. Fletcher, A. Deletic and Y. Zinger (in press). Optimisation of the treatment efficiency of biofilters; results of a large-scale laboratory study. *Water Research.*

Some results…

… but careful design is required to ensure removal of N

- some plant species are no more effective than non-vegetated filters

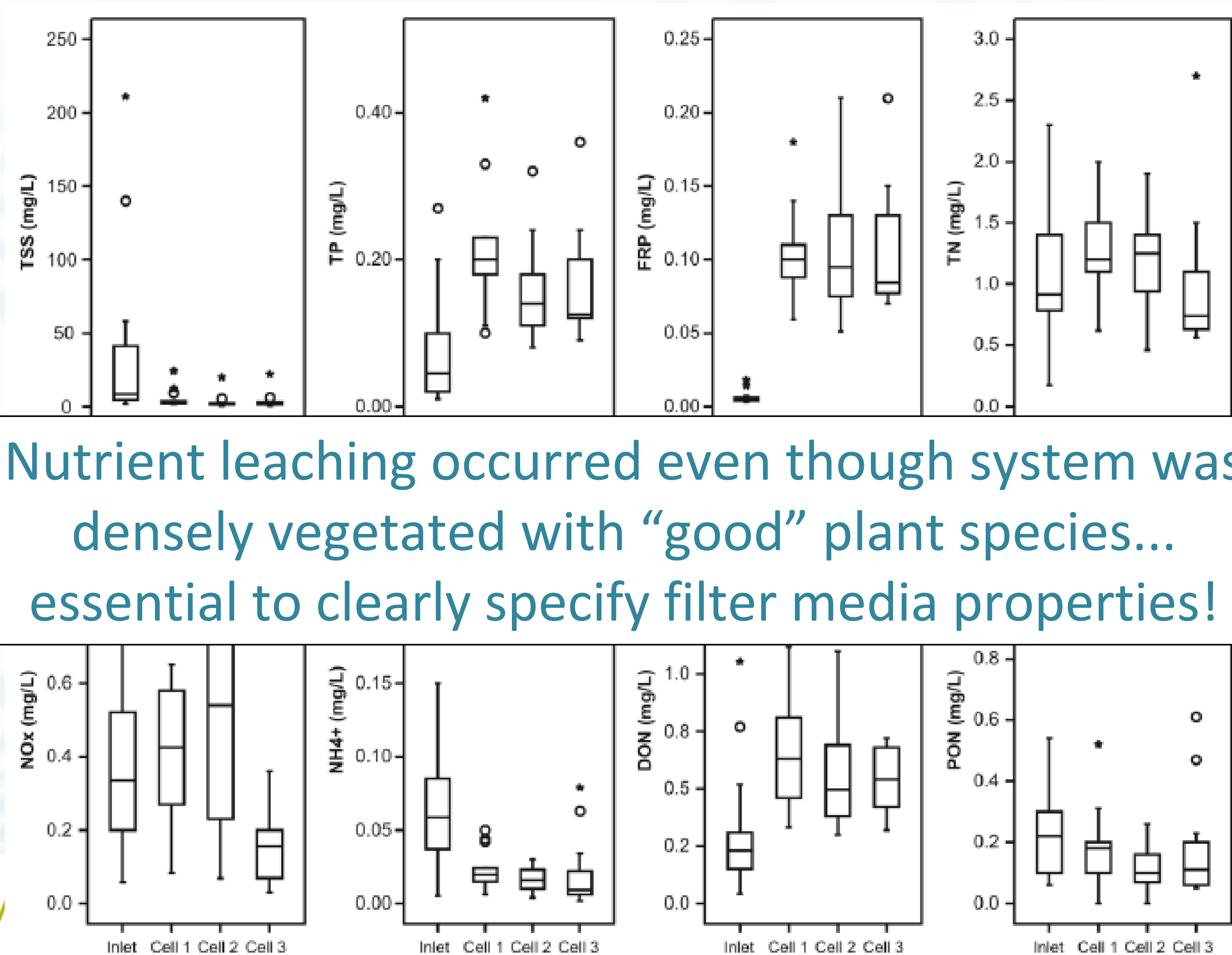


C – *Carex appressa*
ME – *Melaleuca ericifolia*
MS – *Microleana stipoides*
D – *Dianella revoluta*
L – *Leucophyta brownii*
NV – non-vegetated

Bratieres, K., T. D. Fletcher, A. Deletic and Y. Zinger (in press). Optimisation of the treatment efficiency of biofilters; results of a large-scale laboratory study. *Water Research.*

An example of poor design (results from the Monash biofilter):

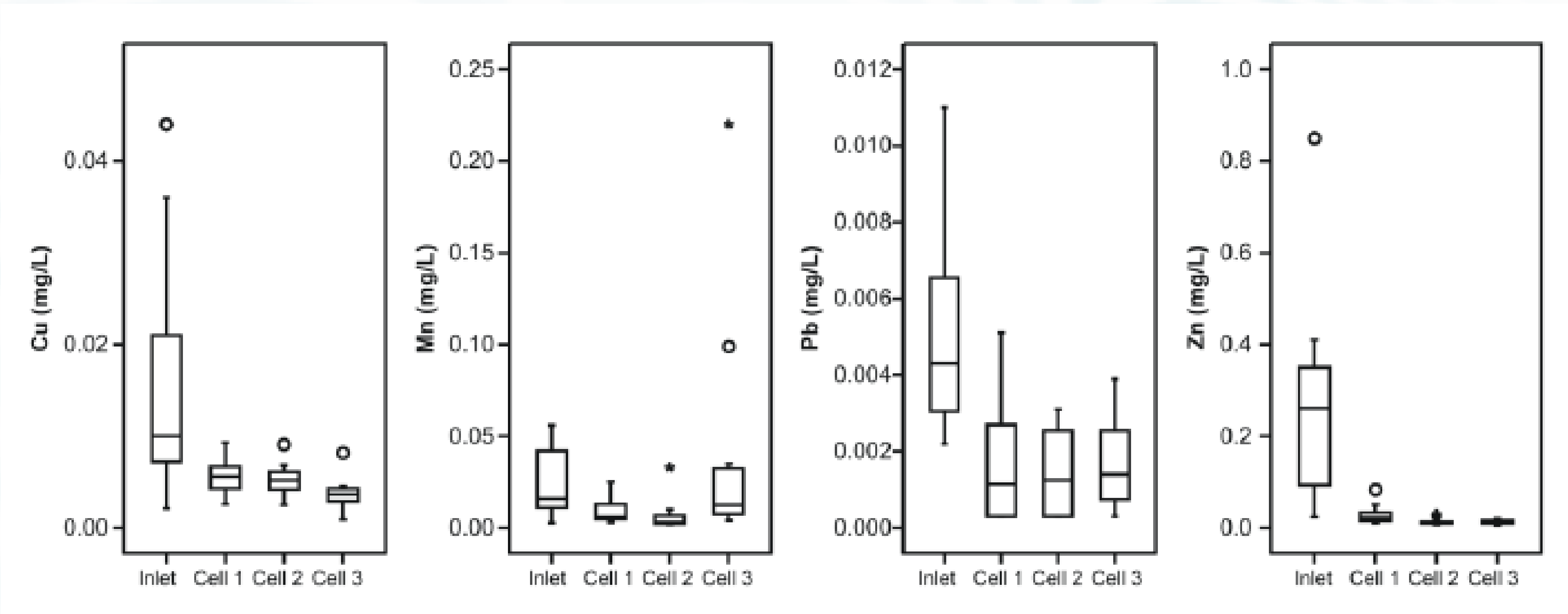
Poor media specification → nutrient leaching...



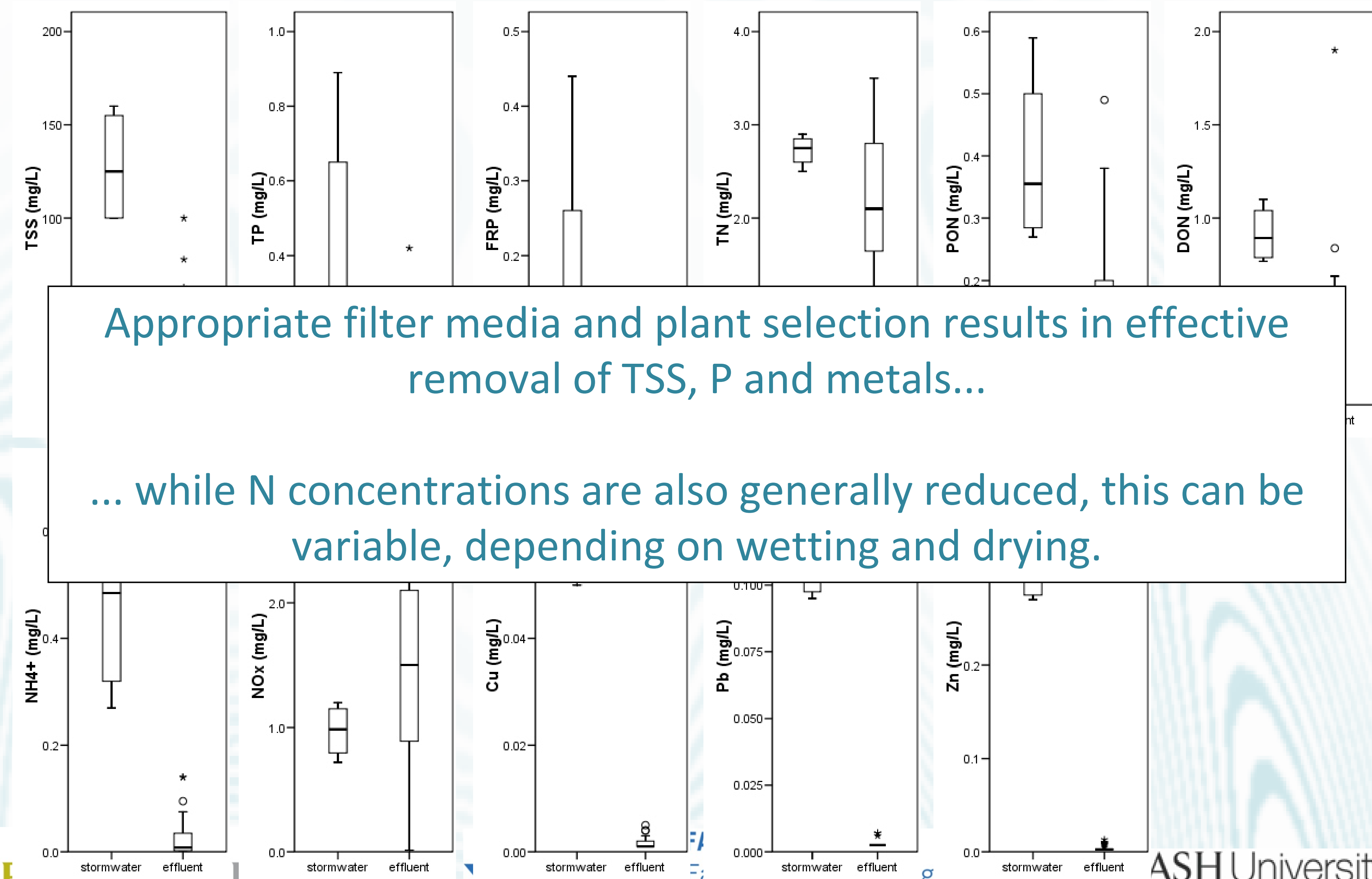
Nutrient leaching occurred even though system was densely vegetated with "good" plant species... essential to clearly specify filter media properties!

An example of poor design (results from the Monash biofilter):

... but concentrations of TSS and metals are always effectively reduced



An example of good design (results from the Saturn Cres biofilter):



Appropriate filter media and plant selection results in effective removal of TSS, P and metals...

... while N concentrations are also generally reduced, this can be variable, depending on wetting and drying.

Load reductions...

Bad Design ← | → Good Design

Load Reduction (%)					
	Monash University, Melbourne	Saturn Crescent, Brisbane (FAWB soil spec)			
	(mean ± standard deviation)	25 Oct 2006	19 Jun 2007	23 Oct 2007	24 Oct 2007
TSS	76 ± 25	91	97	88	94
TP	-398 ± 559	85	90	82	87
FRP	-1271 ± 1067	91	96	75	58
TN	-7 ± 72	17	66	28	31
NO_x	-13 ± 93	-41	33	-47	-33
NH_4^+	64 ± 42	98	99	86	99
DON	-129 ± 232	53	59	73	32
PON	38 ± 55	61	83	88	82
Cd	-	89	94	91	89
Cu	67 ± 23	97	99	98	97
Mn	38 ± 53	-	-	-	-
Pb	80 ± 15	97	99	98	98
Zn	84 ± 26	99	99	99	99

Pathogen Removal

- Removal performances showing *overall* average for sampling after a *wet period*, and after a *dry period*:

	Overall Average Removal	After Wet Period	After Dry Period
C. Perfringens	99.7% (CV =1.1%)	99.6% (CV=1.6%)	99.8% (CV=0.2%)
E. coli	82.1% (CV =38.5%)	98.2% (CV=2.7%)	68.4% (CV=54.5%)
FRNA phages	96.1% (CV=31.3%)	99.6% (CV=2.5%)	93.3% (CV=43.0%)

- Drought period:
  - Reduces mean performance
  - Amplifies differences between configurations
  - Increases variability in results

Pathogen Removal

- Removal performances showing *overall* average, *only SAZ* average and *all but SAZ* average:

	Overall Average Removal	Only SZ Columns	Overall Average Excluding SZ Columns
C. Perfringens	99.7% (CV =1.1%)	99.0% (CV=2.7%)	99.9% (CV=0.3%)
E. coli	82.1% (CV =38.5%)	97.3% (CV=7.0%)	79.5% (CV=42.1%)
FRNA phages	96.1% (CV=31.3%)	73.6% (CV=104.3%)	99.99% (CV=0.1%)

➡ **statistically** significant effect (**$p<0.001$**) of the presence of a submerged zone (SAZ) on the removal of *E. coli* and FRNA phages

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Pathogen Removal

- Removal performances showing *overall* average, *only SAZ* average and *all but SAZ* average:

	Overall Average Removal	Only SZ Columns	Overall Average Excluding SZ Columns
C. Perfringens	99.7% (CV =1.1%)	99.0% (CV=2.7%)	99.9% (CV=0.3%)
E. coli	82.1% (CV =38.5%)	97.3% (CV=7.0%)	79.5% (CV=42.1%)
FRNA phages	96.1% (CV=31.3%)	73.6% (CV=104.3%)	99.99% (CV=0.1%)

Columns with SAZ enhance *E. coli* (97% - CV=7%)

-> moisture buffering capacity reduces formation of cracks

However, SAZ columns reduce FRNA removal performance

-> moist zone promotes survival and multiplication of bacteriophages

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Optimising Treatment Performance

- Filter media: follow FAWB's Guidelines for Soil Filter Media in Bioretention Systems
  - Minimise phosphorus and organic matter content to avoid nutrient leaching
- Vegetation: *Carex appressa, Melaleuca ericifolia*
  - *M. ericifolia* has a longer establishment phase
- Incorporate a submerged zone to avoid nitrogen spikes following dry periods

  OR

  Promote exfiltration for higher load reductions

How long will biofilters work?

- Infiltration capacity
  - Surface clogging
  - Structural stability
- Treatment performance
  - Accumulation of toxicants
  - Breakthrough of pollutants
- Longevity of vegetation community

How long will biofilters work?

Hoyland St, Brisbane

- Constructed in 2001
- Infiltration capacity
  - $K_{s\ ini}$ ~ 600 mm/hr
  - K_s currently ~ 200 mm/hr
- Treatment performance
  - Concentration reductions
    - >50% TP
    - >70% TN
  - Loads?

Recap...

- Infiltration capacity will decrease initially but will recover as plants mature
  - Plant roots help to maintain porosity of filter media
  - Dense planting helps to break up any surface clogging that may occur
- Peak flows and runoff volumes will be significantly reduced
- If designed properly, the following pollutant removal performance can be expected:
  - >95% removal of suspended solids
  - >90% removal of heavy metals
  - >85% removal of phosphorus
  - >50% removal of nitrogen
  - Good for pathogens