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Essential Criteria for Establishing Resilient, Robust Bioretention Media

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With many thanks to:
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Similar Settings for LID/GI Research

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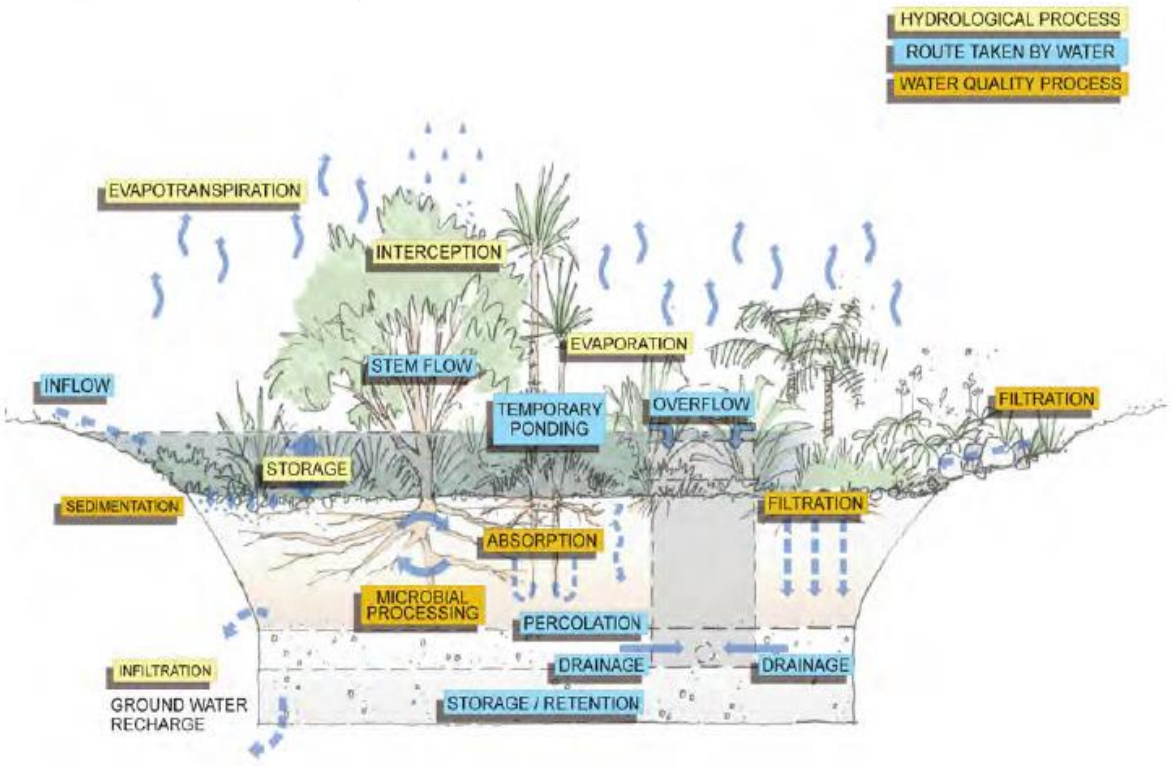
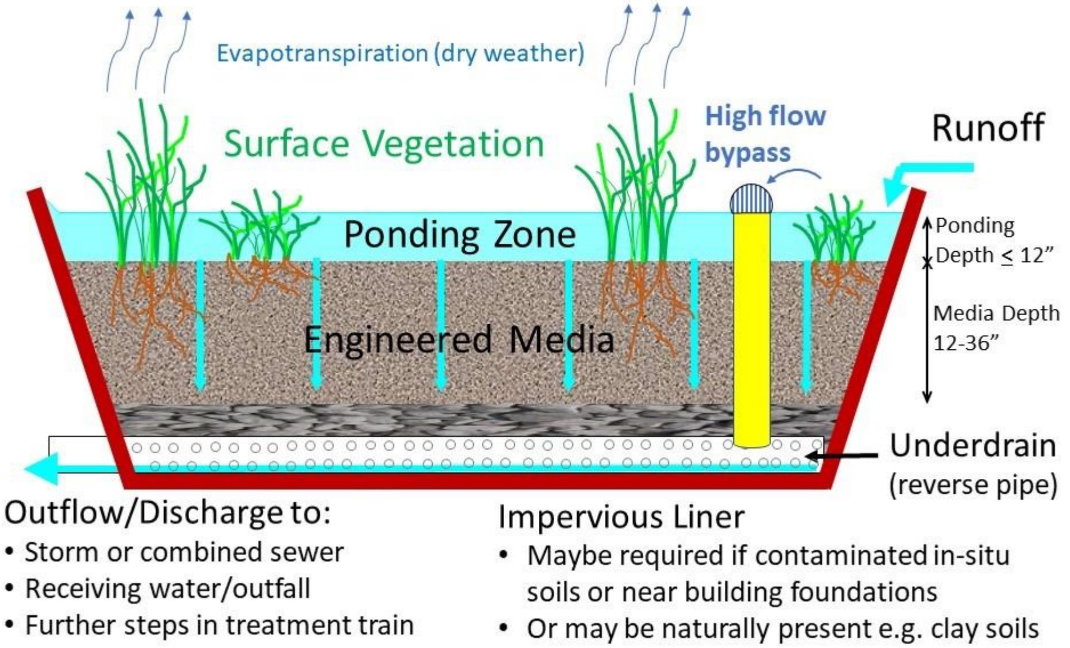
Objective

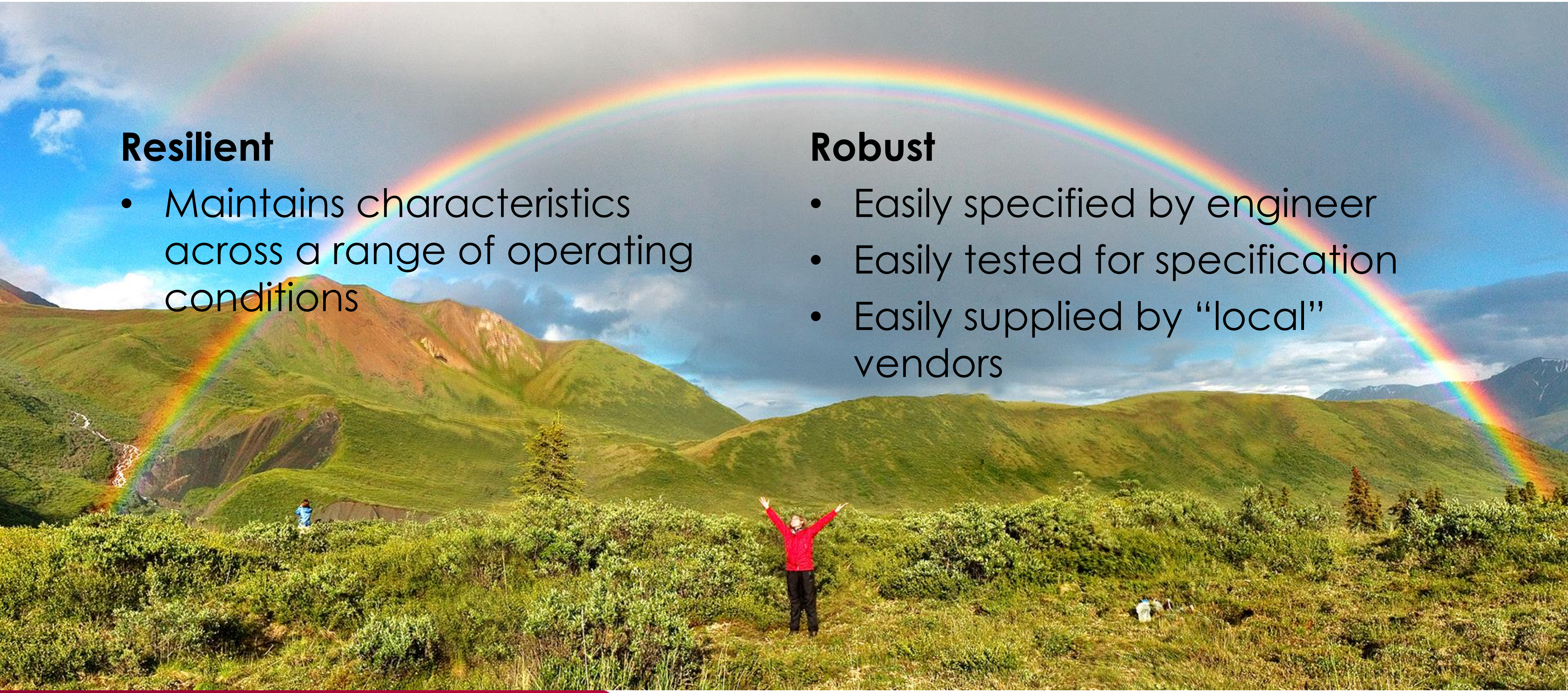
Explore relationships between engineered media properties and bioretention's "success."



Source: NSCC Bioretention Guidelines (2008)



Resilient and Robust?



Resilient

- Maintains characteristics across a range of operating conditions

Robust

- Easily specified by engineer
- Easily tested for specification
- Easily supplied by “local” vendors

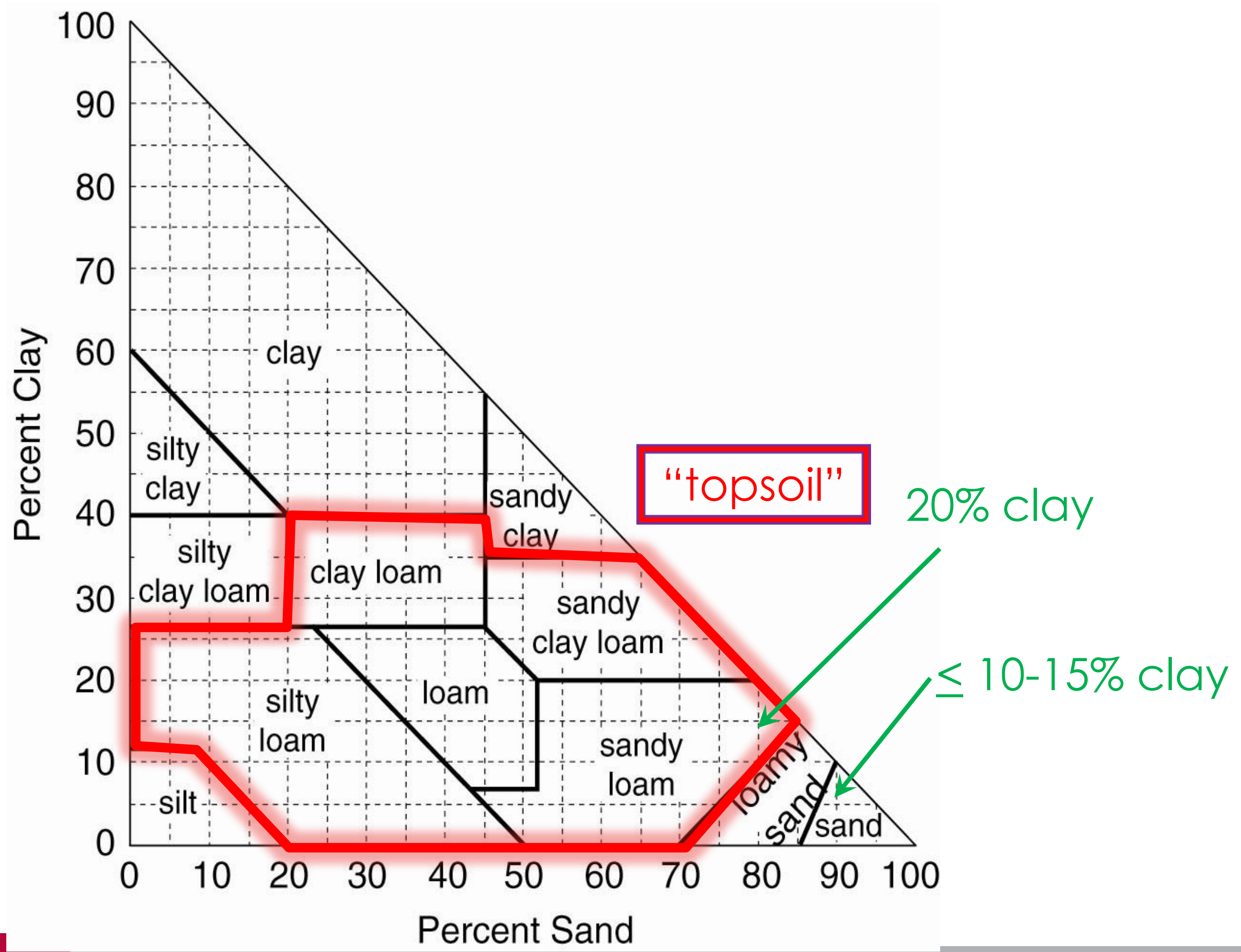
Fill Media: key functions

- Allow adequate surface infiltration and permeability to prevent water ponding for extended periods → minimum permeability
- Allow adequate contact time for pollutant removal → maximum permeability
- Remove, not contribute contaminants
- Remain structurally stable → maintain dispersed flow, resilient to shrinking, compacting, cracking or structural collapse
- Support healthy plant growth

Bioretention Media "Recipes"

Late 1990s-Early 2000s

- 40% "topsoil", 30% sand, 30% compost
- 60% "loamy sand", 40% compost
- In situ soils amended with compost and/or sand



Bioretention Media "Recipes" (>2005)

"North Carolina Mix"[1]	"Auckland Mix"[2]	Melbourne: Facility for Advanced Water Biofiltration (FAWB)[3]
85-88% sand *by volume*	90% aggregate (eg sand) *by volume*	< 6% clay (<6 mm)
8-12% fines (Clay+Silt) *by volume*	10% well-aged compost	< 5% organic matter
3-5% organics		no natural topsoil
		up to 10% vermiculite or perlite

- **NJ DEP:**
- 85-95% sands, ≤ 25% of the sands as fine or very fine sands; measured *by weight*
- ≤15% silt and clay with 2% to 5% clay content.
- 3-7% organics (e.g. compost)
- Test hydraulic conductivity in field or lab

1. Hunt, W. F., & Lord, W. G. (2006)
2. Fassman et al. (2015)
3. FAWB (2009)

Puget Sound (Washington) Partnership

(Hinman et al. 2012)

Hydrology/Hydraulics
- PSD
- "Permeability"

Water Quality & Plant Support
- pH
- C:N
- Cu & Zn content
- P, Al, Fe
- CEC
- OM stability

6 6.1 Bioretention

6.1.2 design

table 6.1.4 Guideline for bioretention soil media.

Component	Parameter	Method	Acceptable Range	Required Test	Recommended Test
Aggregate	Aggregate Gradation	ASTM D 422	Sieve Size / Percent: 3/8 inch 100; No. 4 95 - 100; No. 10 75 - 90; No. 40 25 - 40; No. 100 4-10; No. 200 2 - 5	X	
	Coefficient of uniformity	ASTM D 422	≥ 4		X
Compost	pH	TMECC 04.11-A	6.0 – 8.5	X	
	Carbon nitrogen ratio	TOC – TMECC 04.01 TKN – TMECC 04.02D	25 carbon: 1 nitrogen. Up to 35:1 when using plants composed entirely of Puget Sound natives.	X	
	Inert material	TMECC 03.08-A	≤ 1%	X	
	Organic content	ASTM D 2974 or TMECC 05.07A	40-65% by dry weight	X	
	Restrict large pieces of compost	TMECC 02.02-B	100% passing 1" sieve	X	
	Feed stock composition	N/A	Feed stock ≤35% Type III stock Feed stock ≥ 65% Type I stock (WAC 173-350-100) Compost vendor must be certified by the US Composting Council STA Program	X	
	Maturity indicator	TMECC 05.05-A	> 80%	X	
	Stability indicator	TMECC 05.08-B	≤ 7	X	

6.1 Bioretention 6

6.1.2 design

Component	Parameter	Method	Acceptable Range	Required Test	Recommended Test
	Copper content	EPA 6020	<750 mg/kg	X	
	Zinc content	EPA 6020	<1400 mg/kg	X	
	Soluble salt	TMECC 04.10-A	<4 mmhos/cm	X	
Bioretention Soil Mix	Mix ratio (aggregate : compost)	N/A	60% mineral aggregate :40% compost	X	
	Permeability rate	ASTM D 2434	Initial rate less than 12 inches per hour at 85% compaction (ASTM D 1557). Long term (corrected initial rate) no less than 1 inch per hour. If using specification herein, assume an initial infiltration rate of 6 inches per hour.	Required if using a BSM other than specified herein.	X
	Organic matter content	ASTM D 2974 or TMECC 05.07A	4-8% (by dry weight)	Required if using a BSM other than specified herein.	X
	Ratio of Oxalate phosphorus and oxalate iron and aluminum	SSSA Mono.9 6-2.3	< 0.25 (> 0.25 indicates potential for phosphorus leaching		X
	Cation exchange capacity	EPA 9081	≥5 meq/100 g dry soil	Required if using a BSM other than specified herein.	

http://www.psp.wa.gov/downloads/LID/20121221_LIDmanual_FINAL_secure.pdf

FAWB (Australia) "Essential" Specifications (2015)

	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 in Testing method
	Clay & silt content	**< 3% (w/w)**	Above this thre is substantially particles also re to migration an
	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 stab collapse from d particles
	Nutrient content	**Low nutrient content** Total Nitrogen **(TN) < 1000 mg/kg** Available phosphate (Colwell) **< 80 mg/kg**	Prevents leachi
	Organic matter content	**Minimum content ≤ 5%** to support vegetation	Although some moisture for ve removal, higher leaching
	pH	**5.5 – 7.5** – as specified for 'natural soils and soil blends' in AS4419 – 2003 (pH 1:5 in water)	To support hea term – without 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	

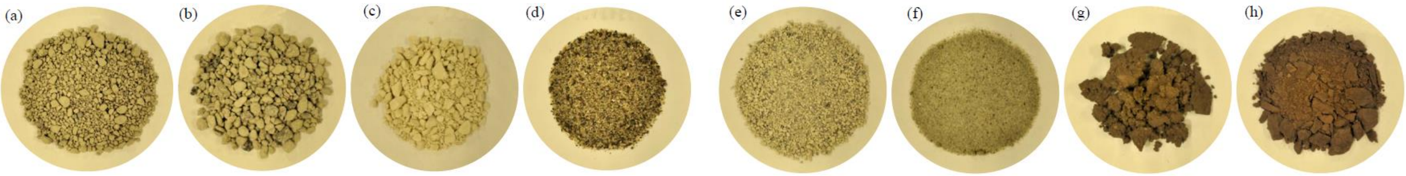
Table 1 Cont.

	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
	Protective surface layer	Include a surface layer 100-150 mm deep overlying the biofilter media. Use a coarser particle size than the media, generally commercially available sands.	Lab studies have successfully demonstrated the potential for this layer to delay clogging and improve treatment performance. Currently being tested in the field.

http://clearwater.asn.au//user-data/resource-files/2015_7_14_-full-adoption-biofiltration-guidelines.pdf

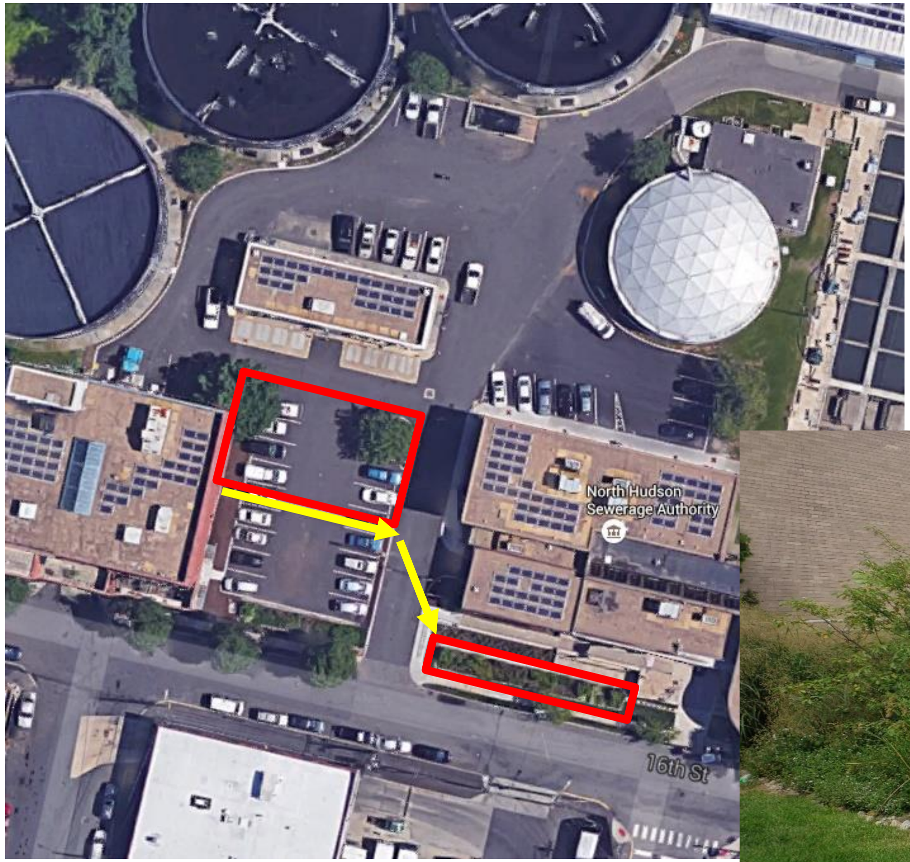
Functional Challenges: Media Specification

- Concerns over long-term clogging
- Public perception of a “problem” with standing water
- Default to sand soil texture or PSD as primary selection criteria
- Specification intent to promote appropriate k_s

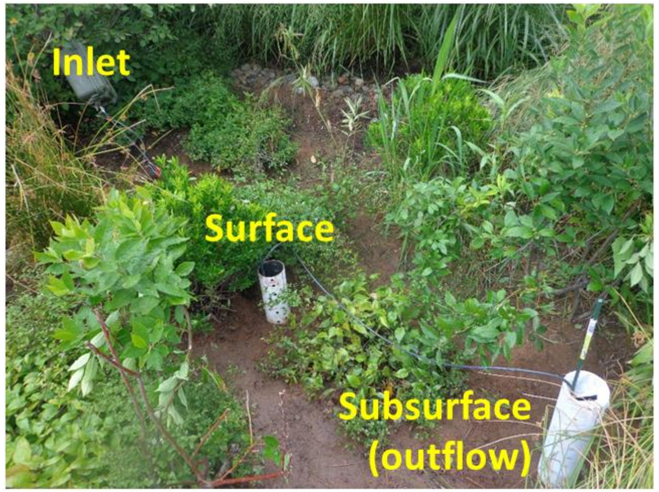


North Hudson Sewer Authority (NHSA)

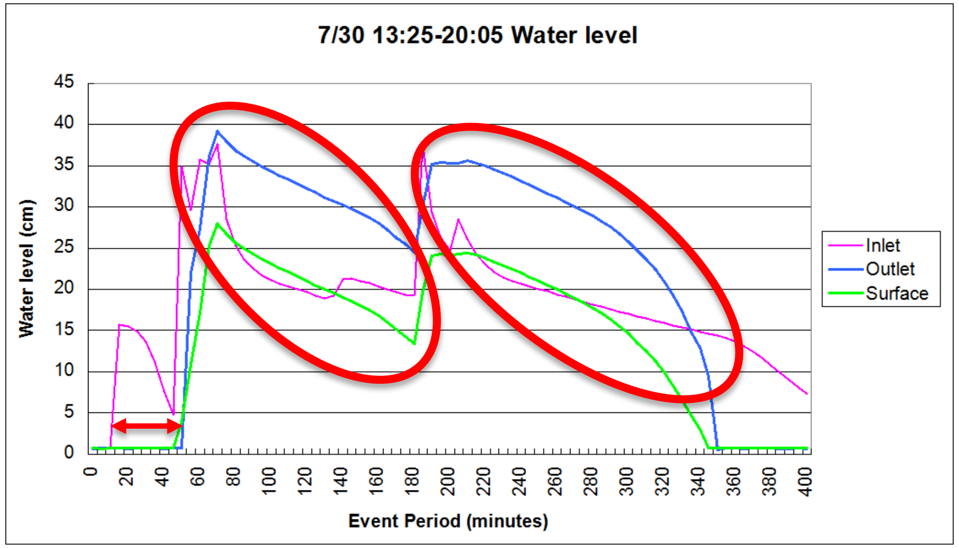
Hoboken, NJ

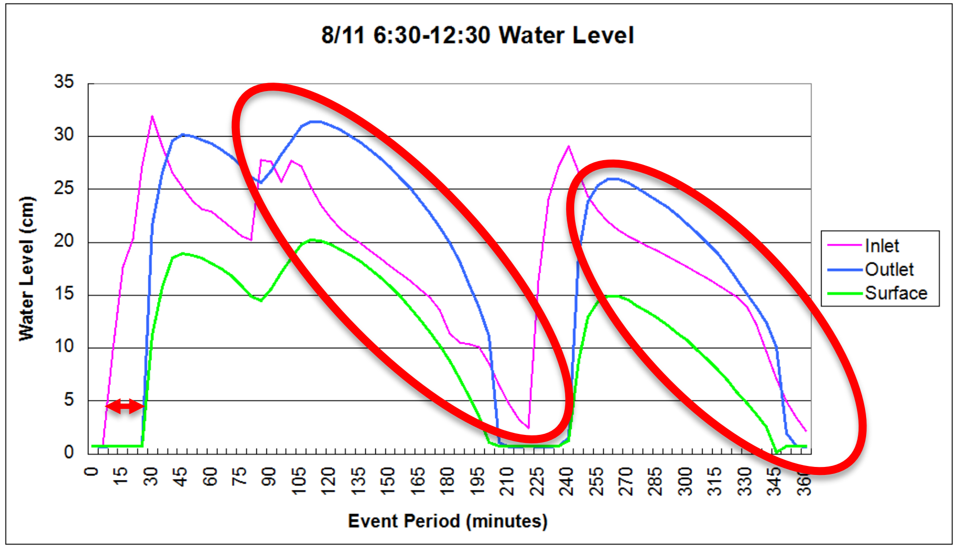


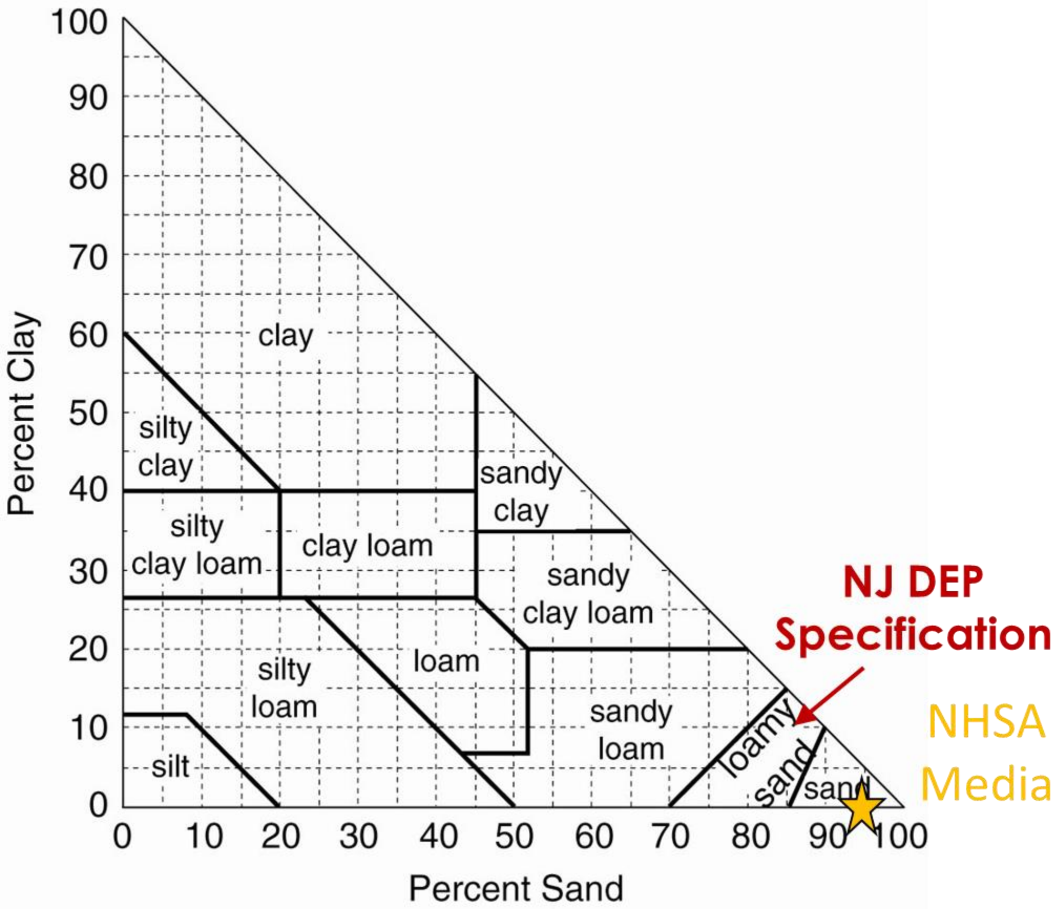
- CSO permittee
- 1st demonstration (retrofit) site
- ~12" media depth over exfiltrating gravel bed
- "inches" above SHWT



NHSA Raw Data: Inflow Rate ≈ Outflow Rate

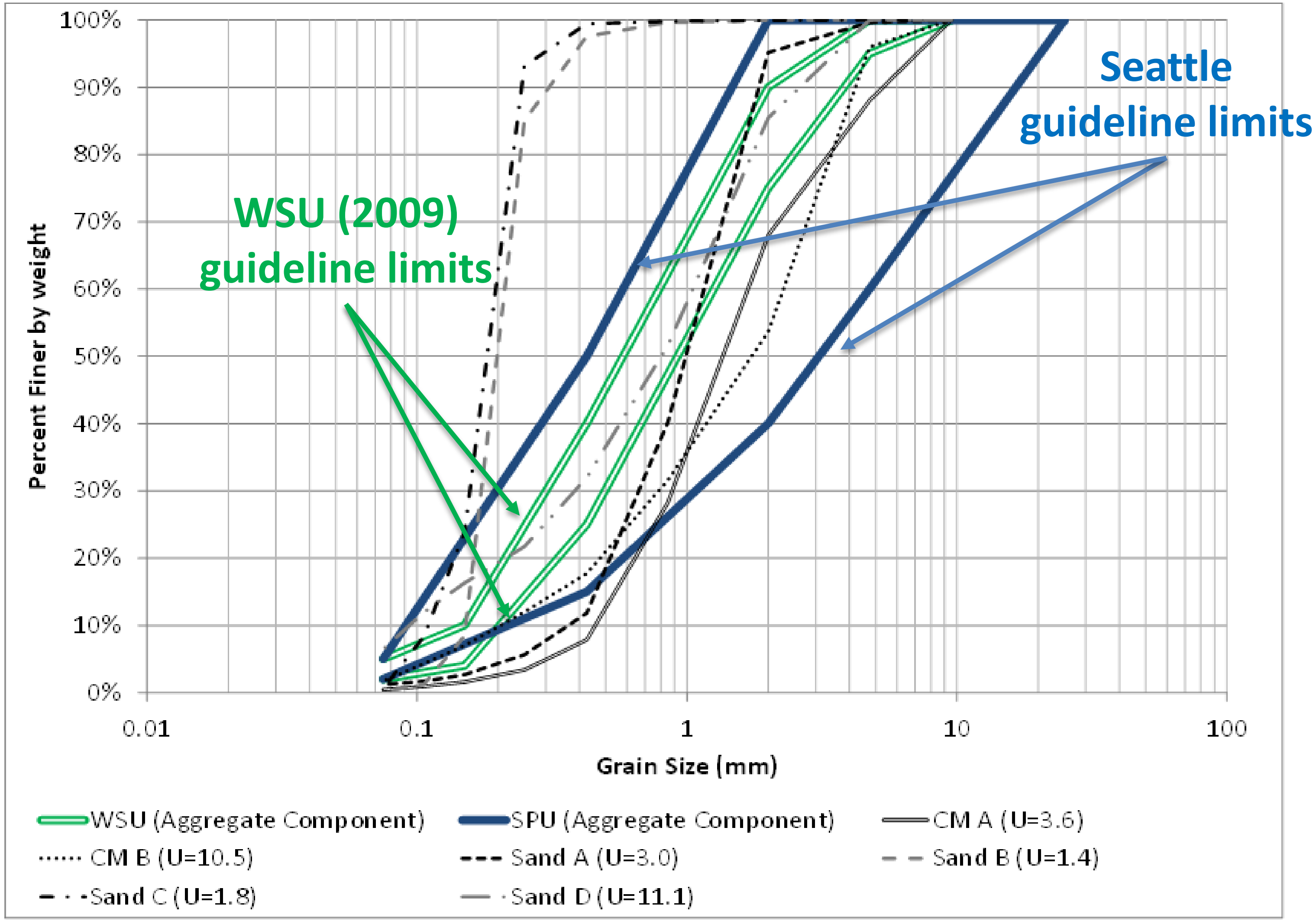






Meaningful Characterization?

Particle Size Distributions

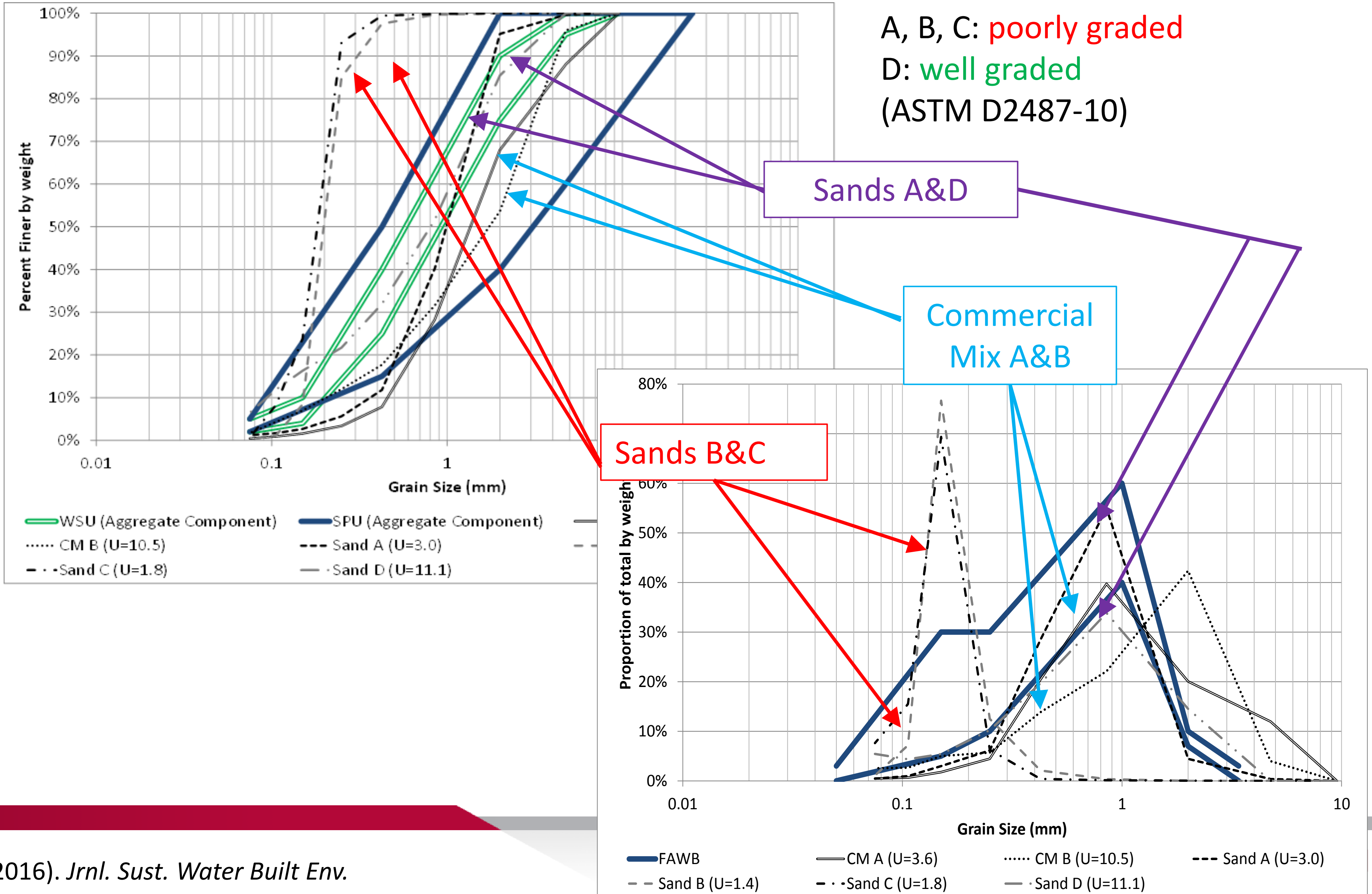


Fassman-Beck et al. (2015). *Jrnl. Sustainable Water in the Built Environ.*

Lab-Measured PSD vs "Suggested" Criteria

(thanks to Simon Wang, ME, UoA)

A, B, C: poorly graded
D: well graded
(ASTM D2487-10)



Fassman-Beck et al. (2016). *Jrnl. Sust. Water Built Env.*

Sizing approaches dependent on media properties

- ~~2-20% of drainage area~~
- Darcy's Law (US EPA 2004)
- Static capture
  - Y% of pore space + bowl volume
  - Bioretention abstraction volume (BAV) → Water retention characteristics from soil & plant science (Davis et al. 2012)

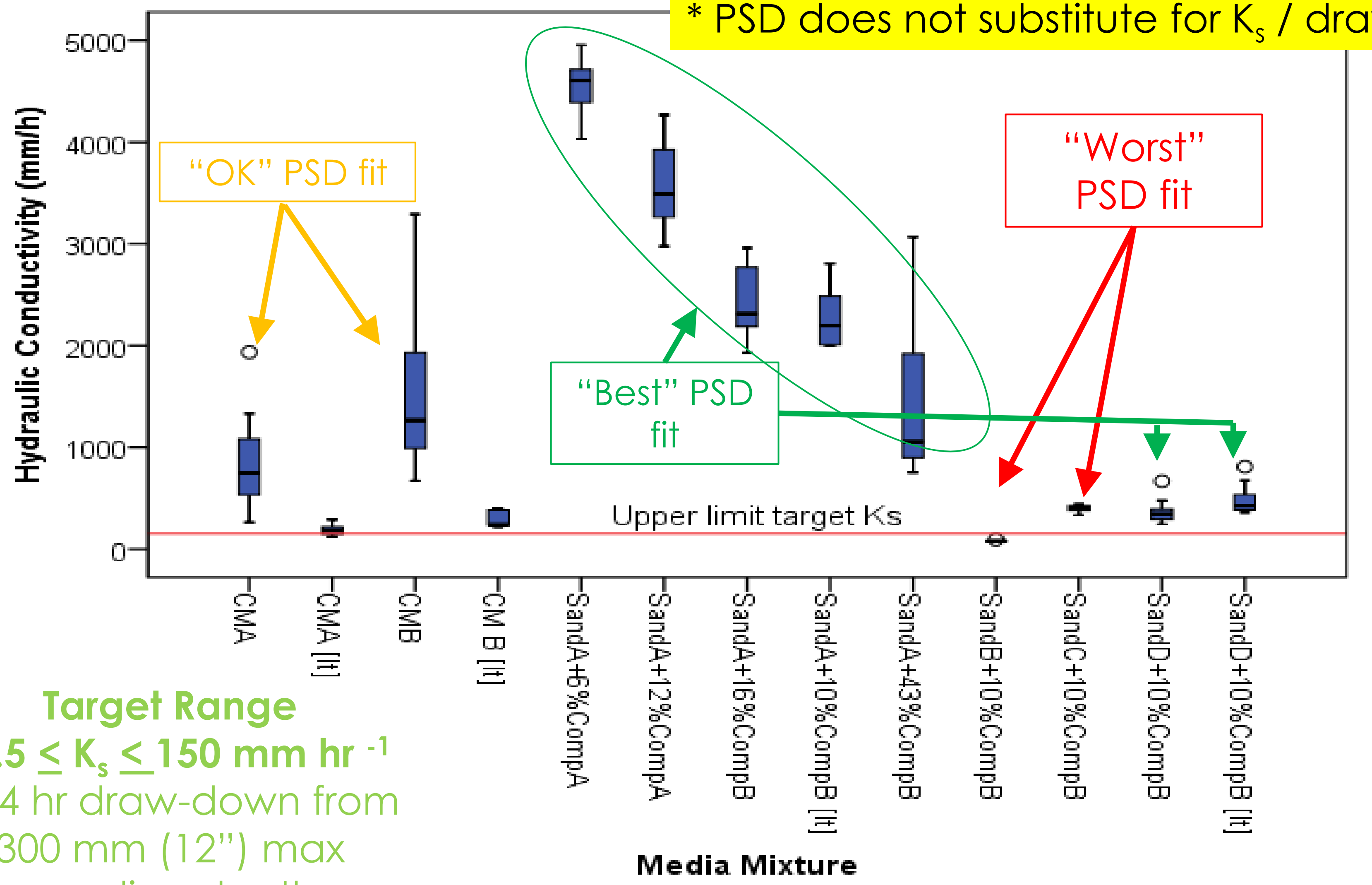
Darcy's Law Rearranged

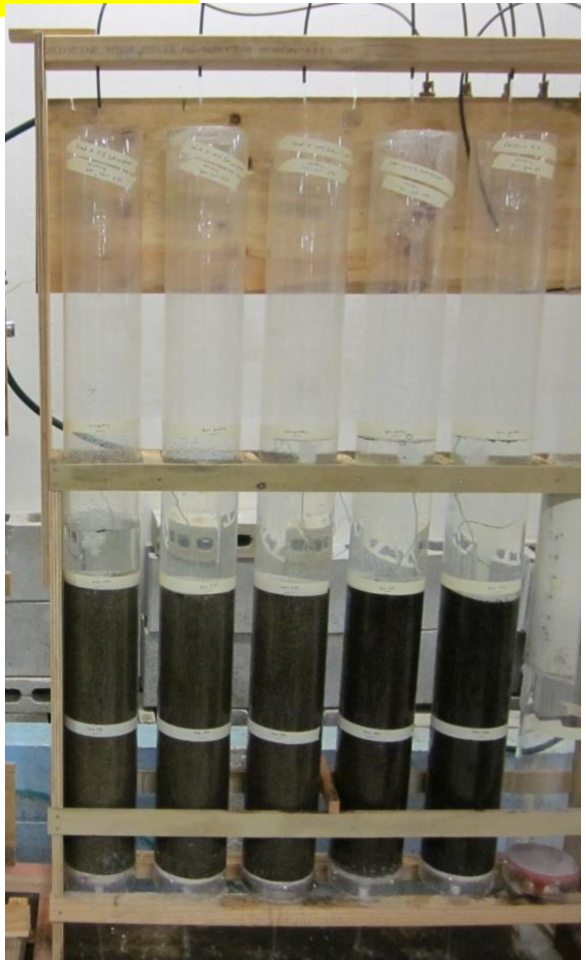
$$A_f = \frac{V_{storage} \times d_f}{k_s \times (h + d_f) \times t_f}$$

A_f	surface area of filter
$V_{storage}$	vol. of runoff to treat/manage
d_f	depth of filter media
h	ave. ponding depth
k_s	saturated hydraulic conductivity
t_f	time to drain through media

Meaningful Characterization?
K_s Relationship (?) to Aggregate PSD

* PSD does not substitute for K_s / drawdown test





Target Range

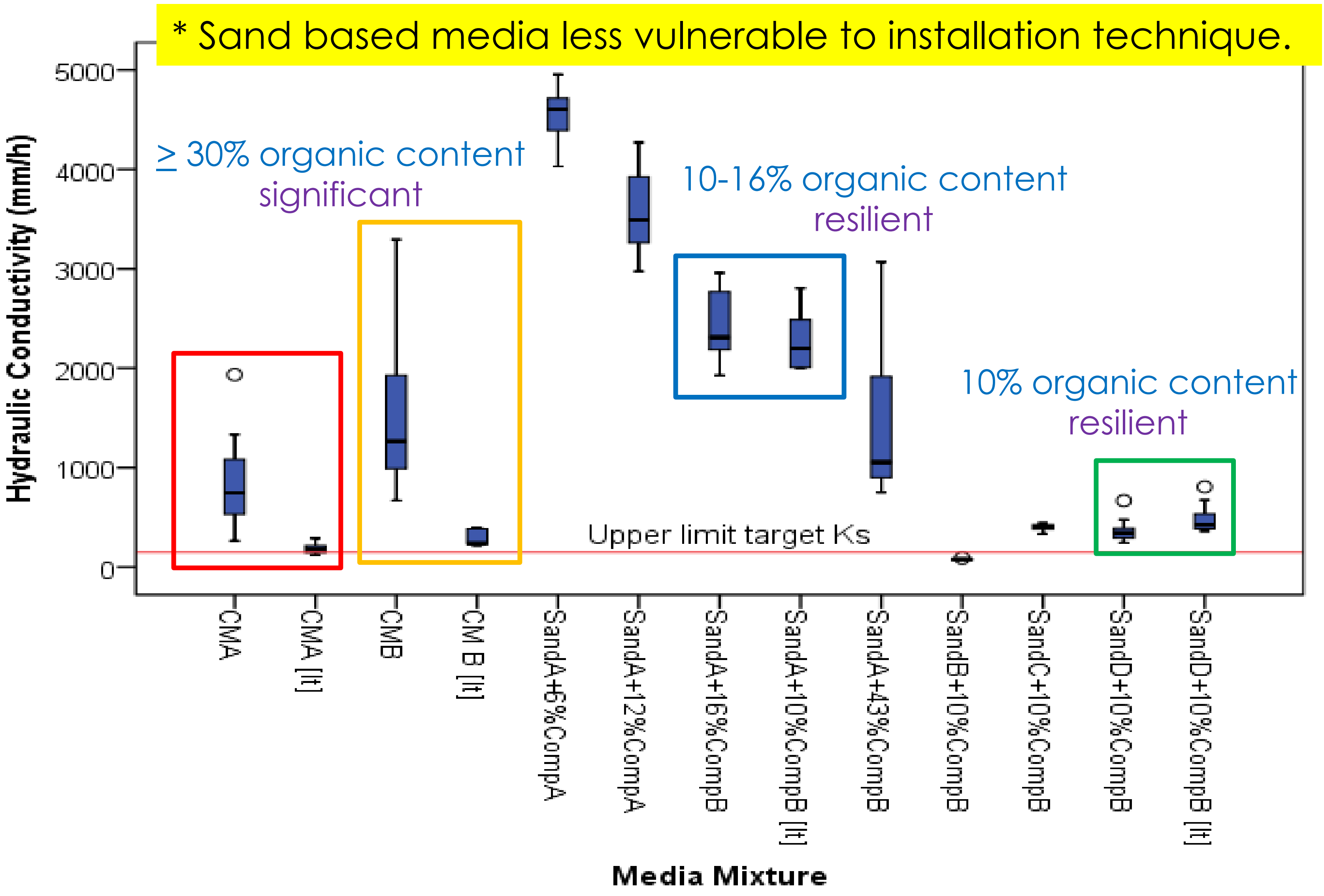
$12.5 \le K_s \le 150$ mm hr $^{-1}$

2-24 hr draw-down from 300 mm (12") max ponding depth

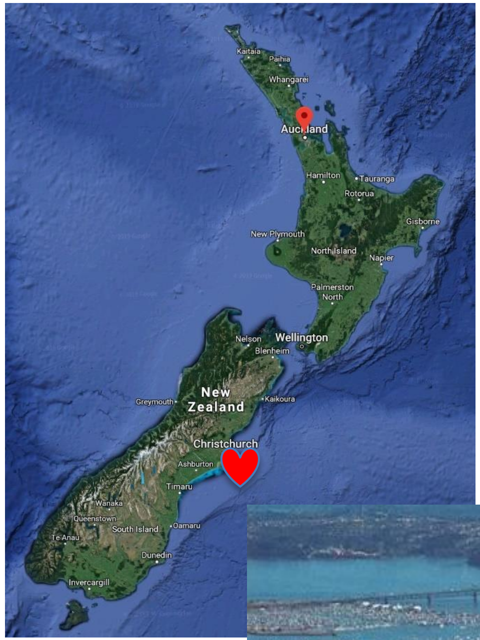
Fassman-Beck et al. (2015). *Jrnl. Sustainable Water in the Built Environ.*

Compaction & Settling Issues?

K_s Response to Compaction Technique



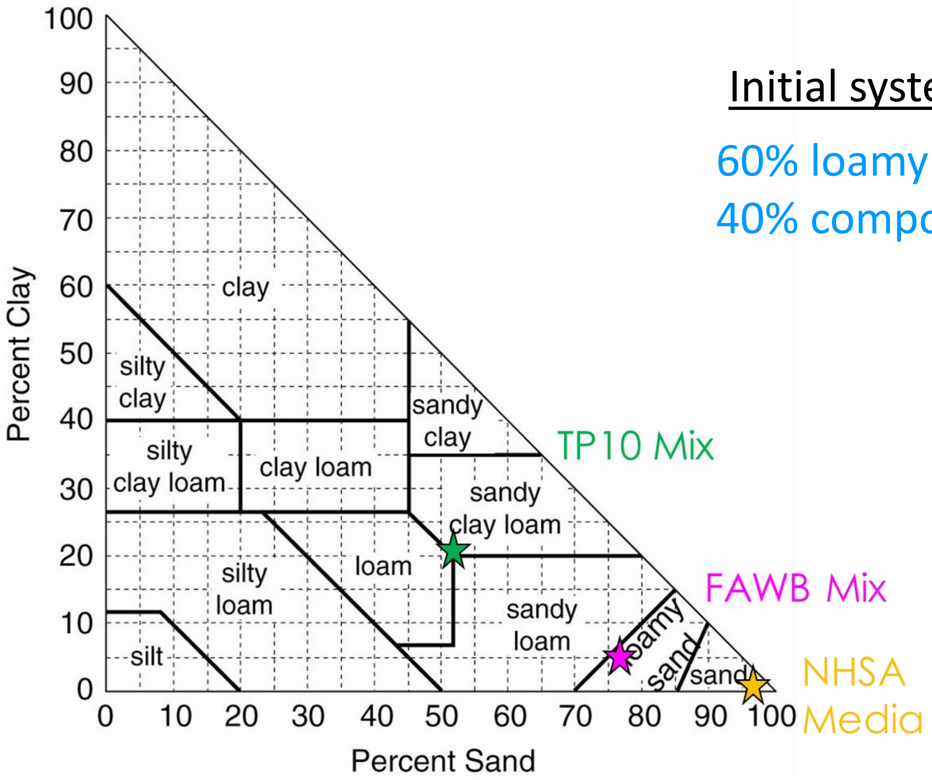
Auckland (NZ) Wynyard Quarter



- Waterfront dining precinct
- Installation specifications driven by urban design objectives

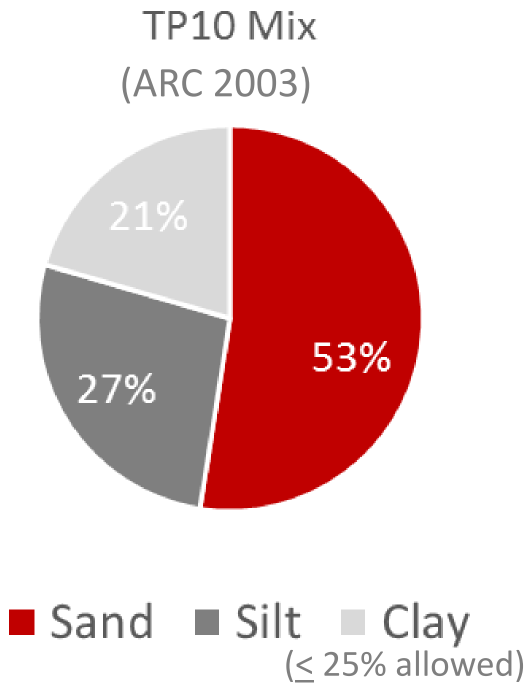
PSD at Wynyard Quarter Rain Gardens

~1-yr post-installation; average of 2 samples per media



Initial systems

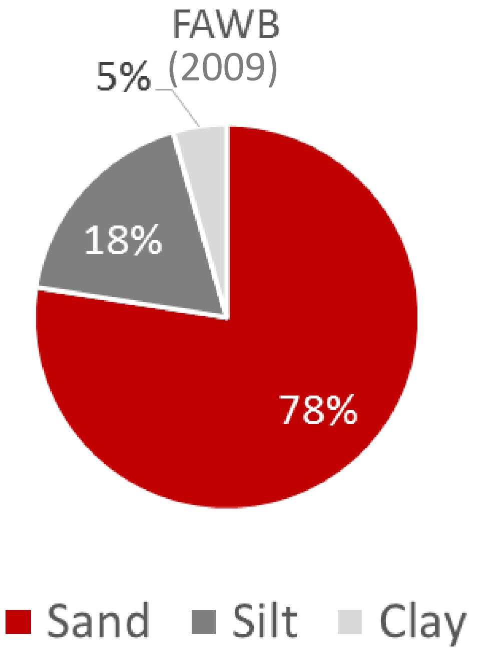
60% loamy sand
40% compost



"loamy sand" media made from compost, beach sand and natural volcanic-ash soil

"Replacement" systems

PSD specified w/
<6% clay (<6 mm)
<5% O.M.
No natural topsoil



pumice sand containing a small proportion of ash soil and no compost

Field-Measured Surface Infiltration Rates at Wynyard Quarter

Media	Low (cm/h)	High (cm/h)	# Samples/ Locations	Method
TP10 Mix				
2011	0	13	Reported across several rain gardens	
2015	79	439	4	twin ring, falling head
FAWB Mix				
2012	231	599	6	twin ring, constant head
2014	241	259	1	flood test

No mulch

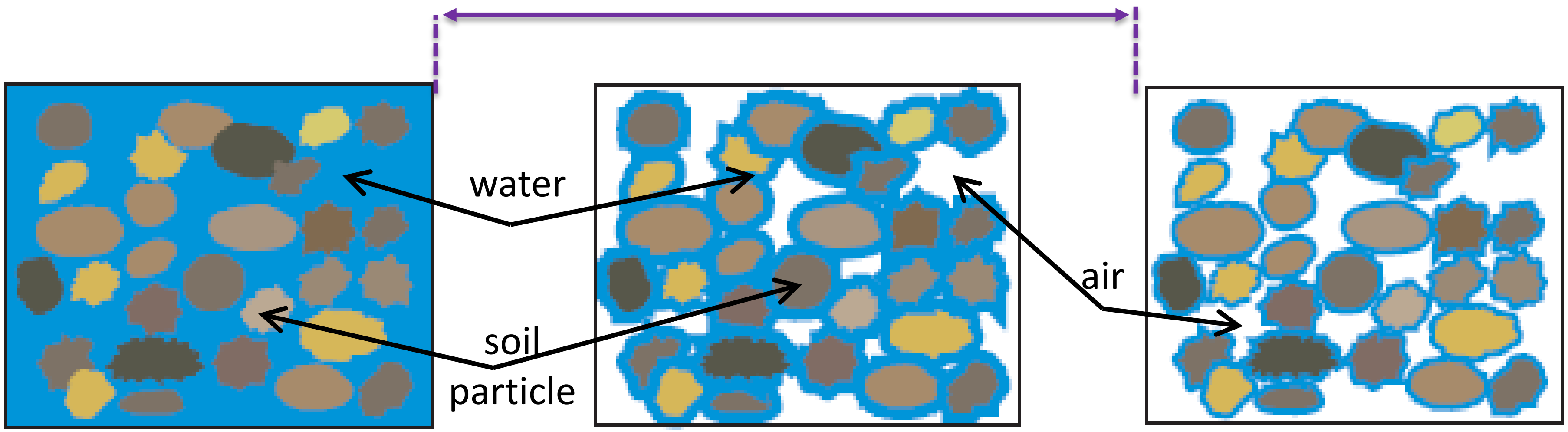
"forked"

↓ Plants/roots ↓

Irrigation needed

Soil Moisture Concepts/ Water Retention Characteristics

Root zone "Bioretention Abstraction Volume" (Davis et al. 2012)



Saturation

All pores are full of water. Moisture content = porosity

Really wet.

Field Capacity

Moisture greater than this drains by gravity.

No more outflow, but soil is still wet.

Wilting Point

Moisture less than this can't be accessed by plants

Very dry to the touch (but there's a teeny amount of water present).

Detention Storage

Plant Available Water aka Available Water Capacity
→ Retention Storage & ET

Meaningful Characterization? Water Retention Characteristics

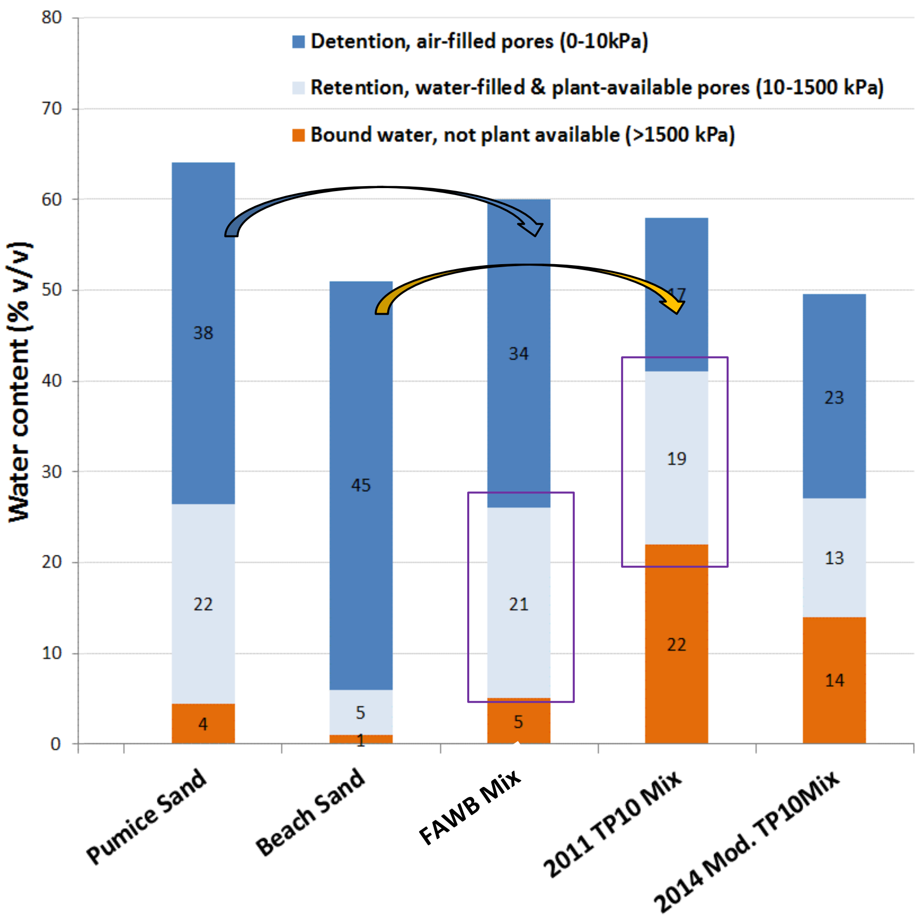
		Marine Sand			Pumice Sand	
		Sand B			Sand D	
Parameter relevance	Measurement	Pure sand	With 10% compost	With 20% compost	Pure sand	With 10% compost
Plant response	Available water capacity	0.054	0.082	0.064	0.252	0.237
Bioretention abstraction volume	Porosity–WP, root zone storage	0.503	0.486	0.477	0.636	0.605
	Porosity–FC, lower media storage	0.449	0.404	0.413	0.384	0.368

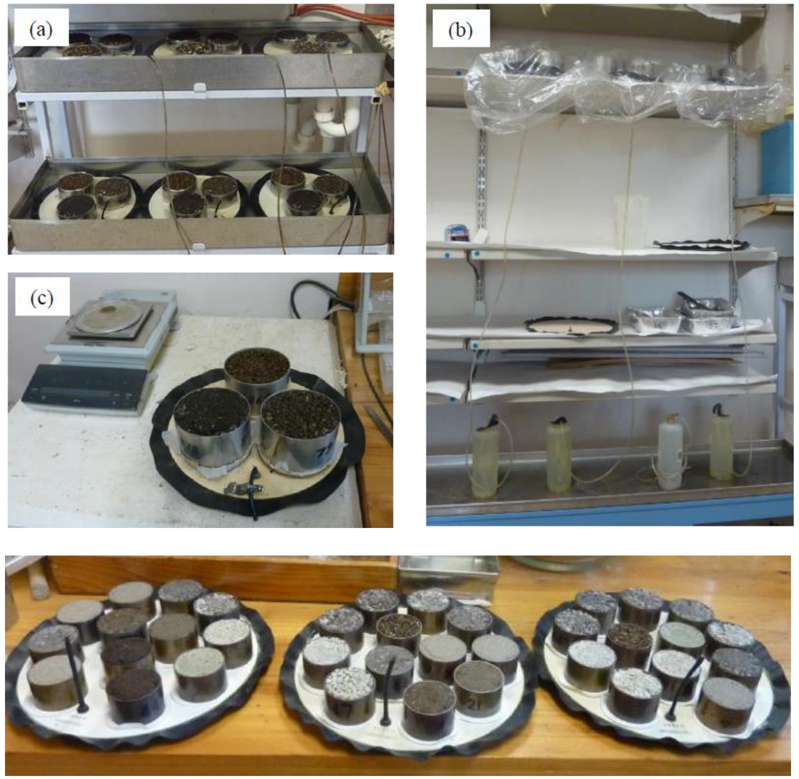
Note: Water content is in units of cubic centimeters per cubic centimeter.

- Available water capacity: in soil science, the amount of water available for evapotranspiration
- Sand mineralogy matters. At low additions, organic content has low impact on marine sand.
- Bioretention abstraction volume (Davis et al. 2012): the amount of water a bioretention cell retains in the media, without exfiltration or underdrain discharge

Fassman-Beck et al. (2015). *Jrnl. Sustainable Water in the Built Environ.*

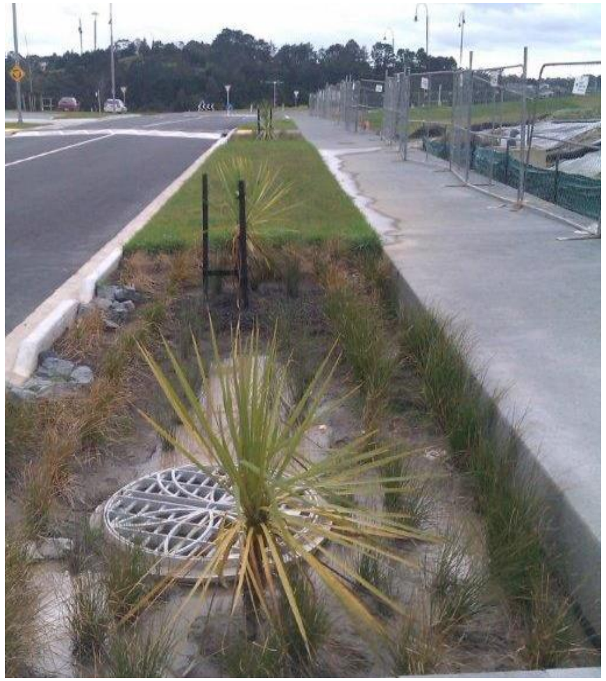
Water Storage Potential
(water retention characteristic data)





Other Observations

- Installation conditions may not indicate long term performance
  - Hydraulic load
  - Catchment sediment load
  - Plant condition
  - A well-designed media does not eliminate maintenance demand
- Chemistry! Compost can be a source of contaminants:
  - Heavy metals from residual pesticides and/or animal care
  - Nutrient rich → Davis et al. for P leaching potential



Conclusions… Resilient & Robust?

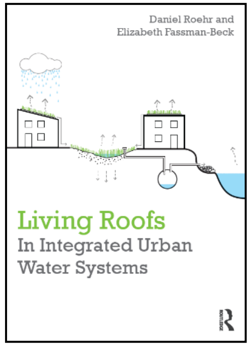
- PSD is a minor factor in determining infiltration rates. Must test k_s!
- Plants are integral to function → influence infiltration rate & recovery of storage capacity
- Not all sands are created equal.
- "Too" sandy media may hinder stormwater management & urban design objectives
- Water retention characteristic more informative (Davis et al. 2012; Fassman-Beck et al. 2016)

There's a lot more than just the media to ensure success…

Oct. 2018 Newly installed

March 2019

Many thanks....



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