Bioretention & High Rate Biofiltration – Research & Performance Updates from the US

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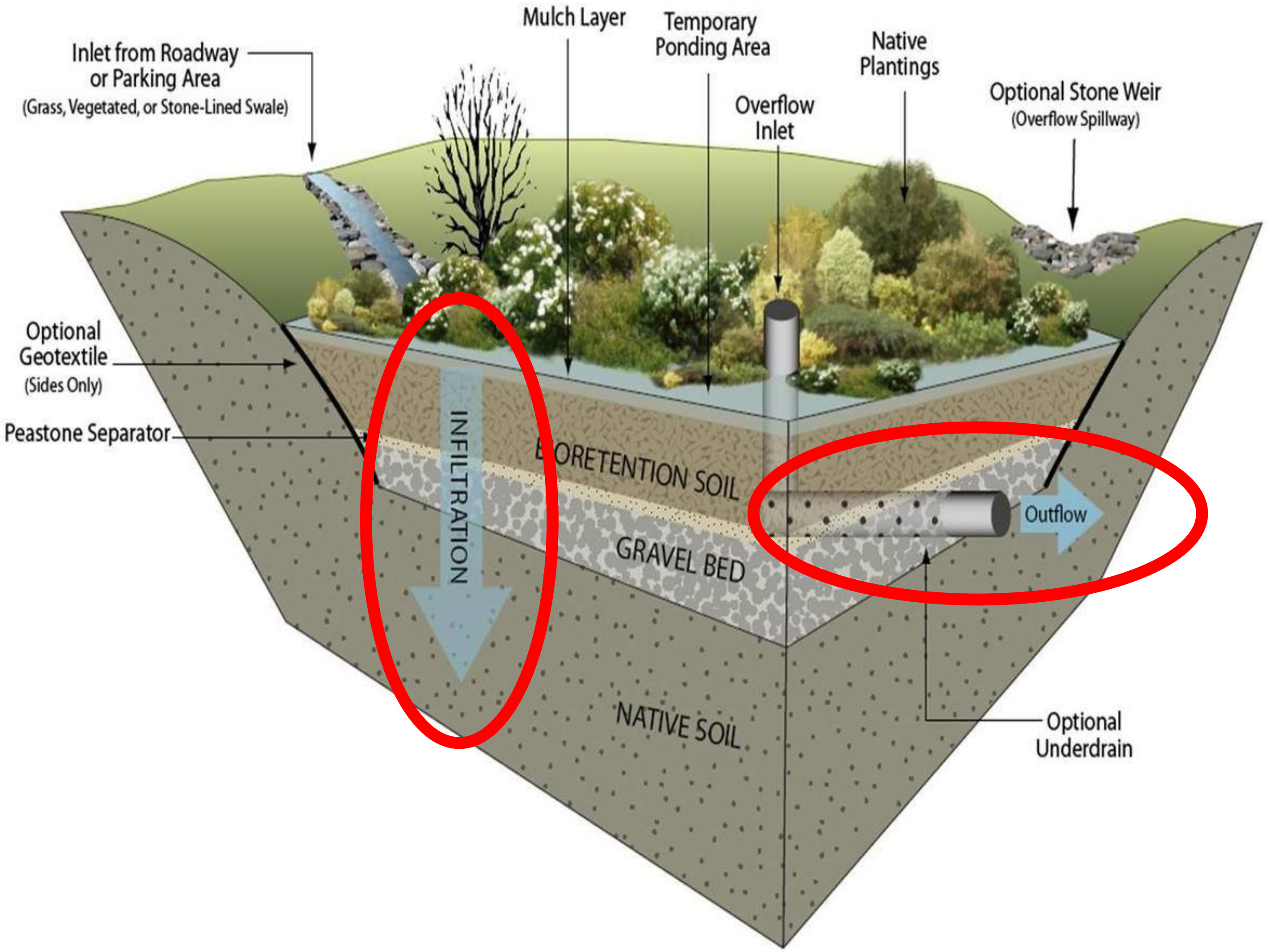
- Research interests: stormwater quality and synthetic runoff

Agenda

- Background
- Bioretention Media
  - Mile High Flood District, CO
  - Minnesota Pollution Control Agency
  - Washington State Department of Ecology
- Bioretention Performance
  - International BMP database
- Data gaps and research
  - Next steps?

https://bluegrasslawn.com/what-is-bioretention

- **SCM** – stormwater control measure (BMP, SUDS, etc)
- **Bioretention** –
  - USDCM Volume 3 Chapter 4 T-03: *“depressed landscape area designed to capture and filter OR infiltrate the WQCV. Also referred to as rain gardens or porous landscape areas (PLDs).”*
  - Infiltration only, or
  - Infiltration + underdrain
- **Biofiltration** –
  - treatment only (no infiltration)



Background

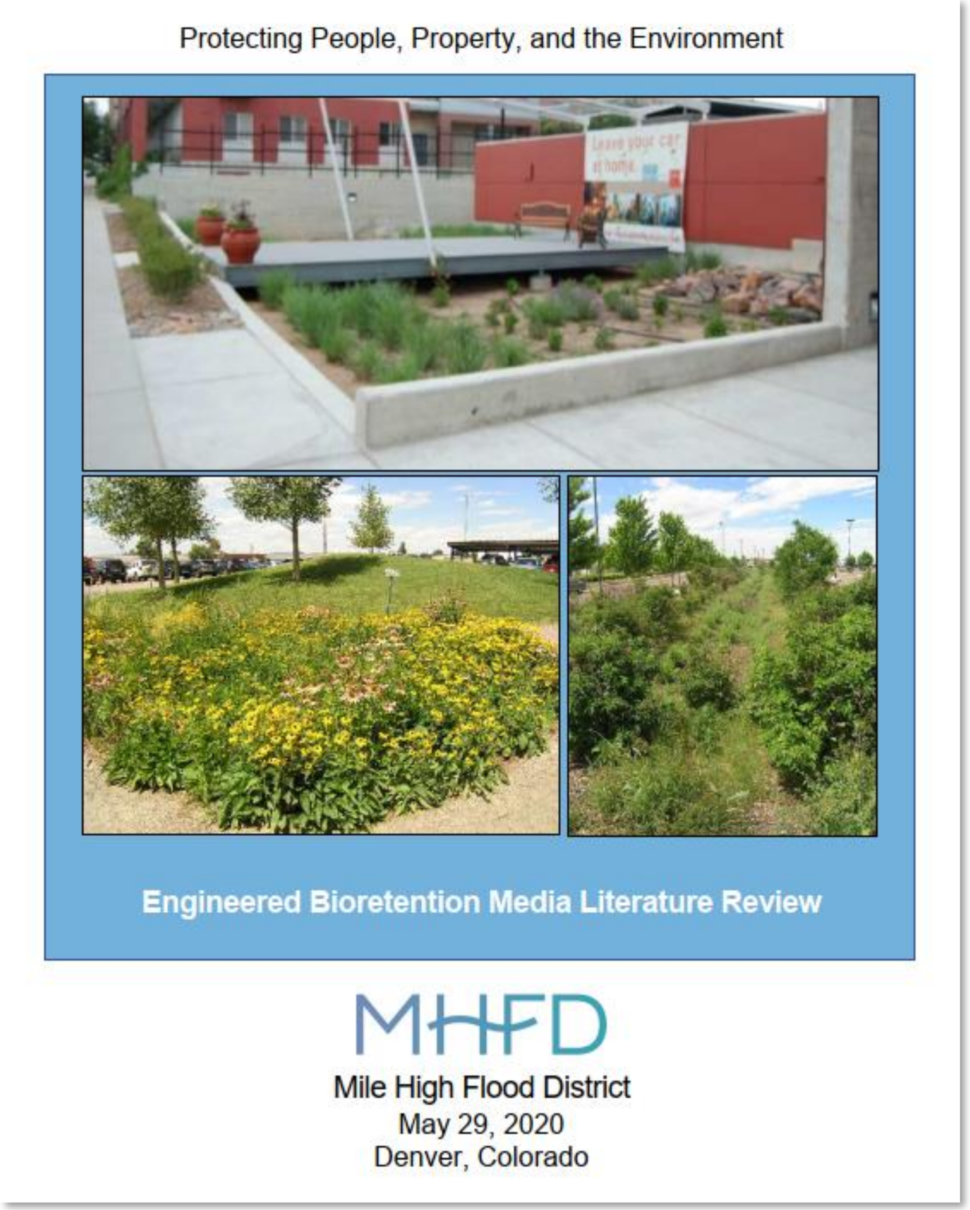
CONTECH ENGINEERED SOLUTIONS

- Most popular SCM
  - Pollutant removal, rate & volume control, aesthetics, habitat, heat island, etc
  - Functioning as designed?
  - Academia vs field installation data gap
- **How do we translate research into practice?**
  - **Media specification**
  - **Regulatory Enforcement**

MPCA https://stormwater.pca.state.mn.us/index.php?title=File:Failing_BMP_1.jpg

Mile High Flood District (MHFD) (Colorado, USA)

- Colorado River provides drinking water to 40 million people
- Updating stormwater criteria manual
- Geosyntec lit review on latest bioretention research to inform new media specs
- https://mhfd.org/bioretention-sand-filters/


Protecting People, Property, and the Environment

Engineered Bioretention Media Literature Review

MHFD

Mile High Flood District

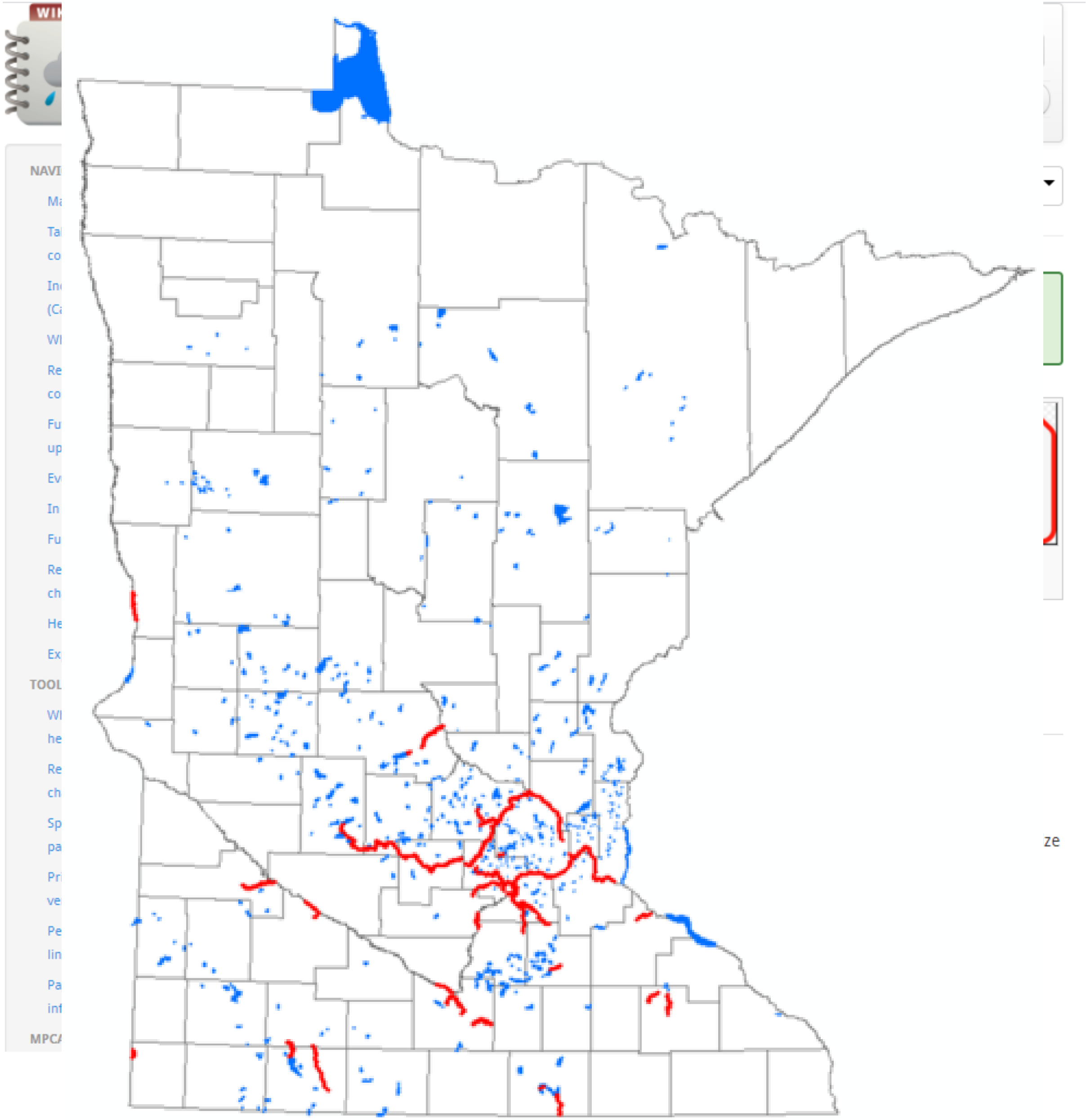
May 29, 2020

Denver, Colorado

Background

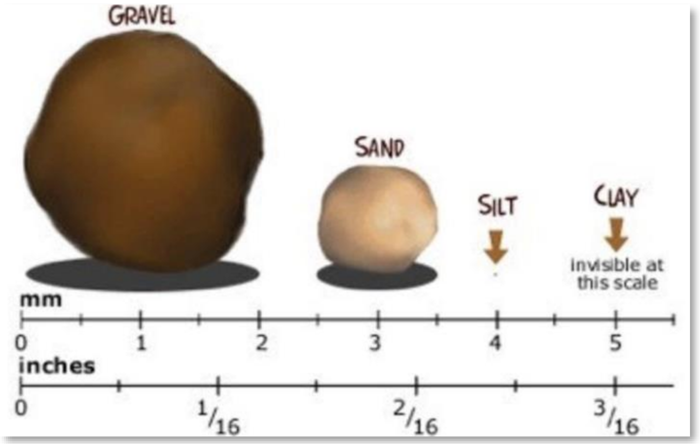
Minnesota Pollution Control Agency (MPCA) (Minnesota, USA)

- Online SW manual
- “Land of 10,000 lakes”
  - 14,444 lakes >10 acres
- 60% total phosphorus reduction required by most public agencies
- Bioretention has a known P leaching problem
- https://stormwater.pca.state.mn.us/index.php/Design_criteria_for_bioretention



Geosyntec & MHFD Bioretention Media Literature Review

- Gradation
- OM content
- Homogeny
- Hydraulic Conductivity
- Loading rate
- Depth



Gradation

- MHFD lit review:
  - More fines
    - Better nutrient removal
    - More field capacity (excess water storage)
    - More frequent maintenance?
      - Larger practice req'd
- MPCA:
  - 6 blends in manual
    - Only 2 recommended for P removal
  - Mix C: NC State water quality blend
    - Recommend <5% clay by volume

Table 1: Current Particle Size Distribution of Bioretention Media Specified by MHFD

Particle Type	Particle Diameter (mm)	Distribution
Sand	0.5 – 2.00	80% - 90%
Silt	0.002 – 0.5	3% - 17%
Clay	< 0.002	3% - 17%

https://mhfd.org/wp-content/uploads/2021/05/Geosyntec-2020-06-03-Bioretention_Media_Literature_Review_Final.pdf

- 85 to 88 percent by volume sand (USDA Soil Textural Classification);
- 8 to 12 percent fines by volume (silt and clay, with a maximum clay content of 5% recommended); and
- 3 to 5 percent organic matter by volume (ASTM D 2974 Method C) MnDOT Grade 2 compost (**See Specification 3890, page 685**) is recommended.

https://stormwater.pca.state.mn.us/index.php/Design_criteria_for_bioretention

CONTECH ENGINEERED SOLUTIONS

Organic Matter

- “60/40 blend” is common in US
  - 60% sand, 40% compost
- Bioretention needs OM to support plant health and retain moisture
- Excess OM can increase field capacity and conductivity
  - however, can lead to nutrient leaching
  - type and amount of OM influence nutrient leaching
- MPCA mix C: 3-5% OM by volume

OR

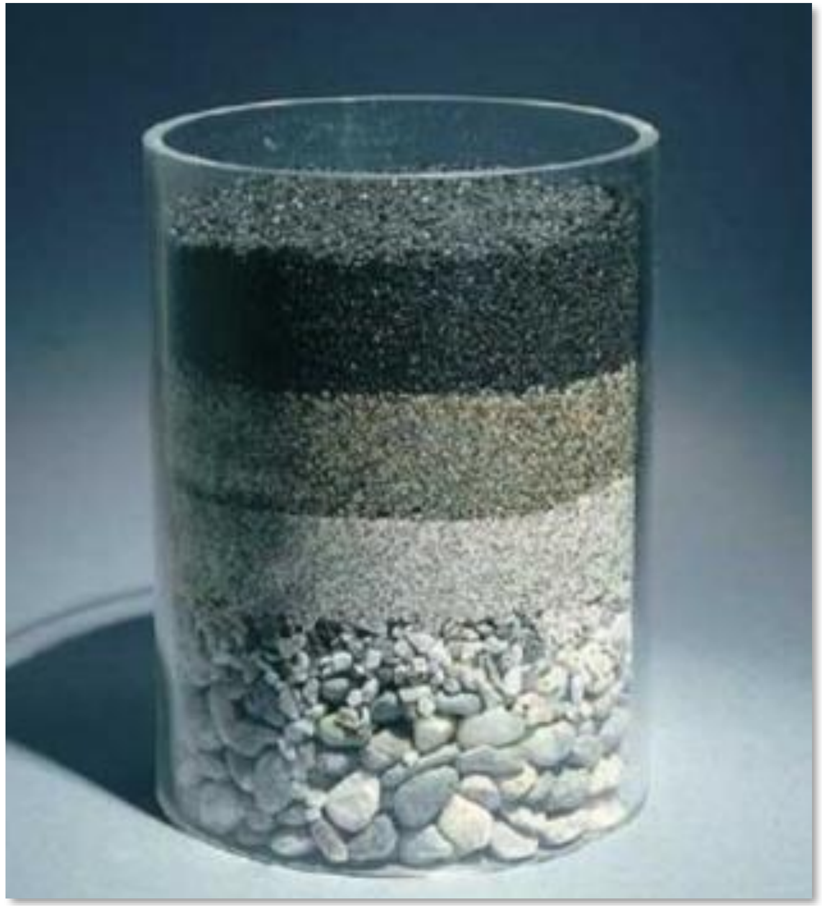
Table 3: Sources of OM in Media Additives

Additive	Advantages	Disadvantages	Source	Amount Recommended
Compost	Can increase moisture content in growing media, supporting plant growth	Can induce nutrient leaching Highly variable mixtures	Herrera Environmental (2015); Colorado Stormwater Center	5% - 20% by volume; <10% of media by volume
Shredded Newspaper	Release relatively low amounts of carbon		Rippy (2015)	
Shredded Mulch*	Effective treatment of heavy metals	Should be site-tested for leaching	Colorado Stormwater Center	< 10% of media by volume
Biosolids	Supports plant growth	Should be assessed for leaching	Brown et al. (2016)	
Wood Chips	Release relatively low amounts of carbon	May float, clogging overflow drain	Rippy (2015)	
Sulfur-limestone	Release relatively low amounts of carbon		Rippy (2015)	
Coconut husk	Can improve soil structure, reduction of heavy metals	Should be assessed for leaching	Colorado Stormwater Center	
Coconut Husk and Sphagnum Peat	High water holding capacity; low nutrient content	May lower media pH	Herrera Environmental (2015)	5% - 20% by volume
Wood ash and Biochar	Promotes biological activity to promote uptake		Herrera Environmental (2015)	5% - 20% by volume
Iron-infused Wood Chips	High potential for lead and phosphorus adsorption	Needs more testing	Herrera Environmental (2015)	5% - 20% by volume

*For information mulch quality variability and quality control measures, see Section 3.2.2 on mulch tendency to leach nutrients.

Homogeny

- Does layering different gradations and non-uniformity help?
- High conductivity over low, greater TP removal
  - Prevents leaching



Bioretention Media

Hydraulic Conductivity

- Typically 25-300mm/hr (1-12”/hr)
- Media spec alone cannot determine conductivity
  - Veg growth and root density/depth
  - Compaction/Installation
  - Maintenance (oversized/undersized?)
- 3.6x decrease in conductivity over 72 weeks
  - Suggests safety factor of 3-4x
  - however, were WQ goals achieved at lower rates or was this a maintenance trigger?
- Specs do not always correlate directly with field conductivity, suggests testing site-specific media selected

- All bioretention growing media must have a field tested infiltration rate between 1 and 8 inches per hour. Growing media with slower infiltration rates could clog over time and may not meet drawdown requirements. Target infiltration rates should be no more than 8 inches per hour to allow for adequate water retention for vegetation as well as adequate retention time for pollutant removal. The following infiltration rates should be achieved if specific pollutants are targeted in a watershed.
  - Total suspended solids: Any rate is sufficient, 2 to 6 inches recommended
  - Pathogens: Any rate is sufficient, 2 to 6 inches recommended
  - Metals: Any rate is sufficient, 2 to 6 inches recommended
  - Temperature: slower rates are preferable (less than 2 inches per hour)
  - Total nitrogen (TN): 1 to 2 inches per hour, with 1 inch per hour recommended
  - Total phosphorus (TP): 2 inches per hour

https://stormwater.pca.state.mn.us/index.php/Design_criteria_for_bioretention

Loading rate (sizing)

- Recommend sizing based on media conductivity, however, can look at loading rate by drainage area to better size for maintenance demands
- MHFD recommends 2% of impervious DA
- MPCA recommends 5-10% of imp DA

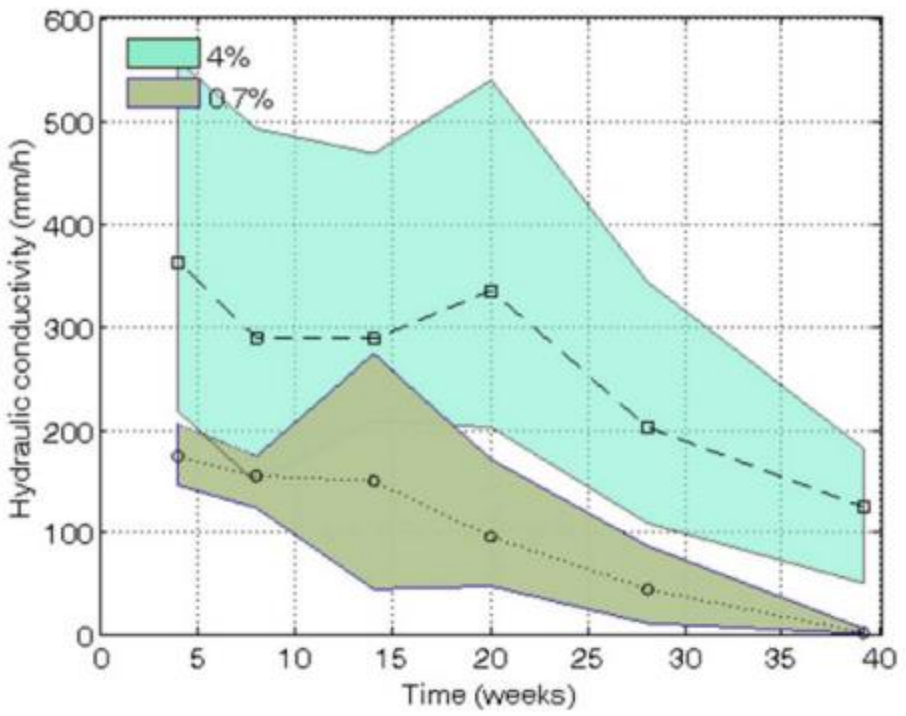


Figure 4: Hydraulic conductivity attenuation for biofilters designed at 4% and 0.7% of their catchment size. The mean is represented by the dotted line and the 95% confidence interval is shaded.

https://mhfd.org/wp-content/uploads/2021/05/Geosyntec-2020-06-03-Bioretention_Media_Literature_Review_Final.pdf

Bioretention Media

CONTECH ENGINEERED SOLUTIONS

Media depth

- MHFD minimum 18 inches, 36 for trees
- Increased filter depth
  - > phosphate removal
  - > N removal (more anoxic potential for denite)
  - > dissolved metals (more sorption sites), extends life of media until breakthrough

Pollutant	Depth of Treatment with upturned elbow or elevated underdrain	Depth of Treatment without underdrain or with underdrain at bottom	Minimum depth
Total suspended solids (TSS)	Top 2 to 3 inches of bioretention soil media	Top 2 to 3 inches of bioretention soil media	Not applicable for TSS because minimum depth needed for plant survival and growth is greater than minimum depth needed for TSS reduction
Metals	Top 8 inches of bioretention soil media	Top 8 inches of bioretention soil media	Not applicable for metals because minimum depth needed for plant survival and growth is greater than minimum depth needed for metals reduction
Hydrocarbons	3 to 4 inch Mulch layer, top 1 inch of bioretention soil media	3 to 4 inches Mulch layer, top 1 inch of bioretention soil media	Not applicable for hydrocarbons because minimum depth needed for plant survival and growth is greater than minimum depth needed for hydrocarbons reduction
Nitrogen	From top to bottom of bioretention soil media; Internal Water Storage Zone (IWS) improves exfiltration, thereby reducing pollutant load to the receiving stream, and also improves nitrogen removal because the longer retention time allows denitrification to occur underanoxic conditions.	From top to bottom of bioretention soil media	Retention time is important, so deeper media is preferred (3 foot minimum)
Particulate phosphorus	Top 2 to 3 inches of bioretention soil media.	Top 2 to 3 inches of bioretention soil media.	Not applicable for particulate phosphorus because minimum depth needed for plant survival and growth is greater than minimum depth needed for particulate phosphorus reduction
Dissolved phosphorus	From top of media to top of submerged zone. Saturated conditions cause P to not be effectively stored in submerged zone.	From top to bottom of bioretention soil media	Minimum 2 feet, but 3 feet recommended as a conservative value; if IWS is included, keep top of submerged zone at least 1.5 to 2 feet from surface of media
Pathogens	From top of soil to top of submerged zone.	From top to bottom of bioretention soil media	Minimum 2 feet; if IWS is included, keep top of submerged zone at least 2 feet from surface of media

https://stormwater.pca.state.mn.us/index.php/Design_criteria_for_bioretention

Vegetation

- Performance
  - Necessary for NOx, ammonia, and phosphate removal
  - Non vegetated leaches N
- Conductivity
  - Root growth and decay creates macropores
    - 0.2”/hr to 50”/hr (switchgrass in bare soil)
  - vegetation extends life by 3-6 years compared to non vegetated sand/peat sand/compost medias
- Volume reduction
  - More plant growth = more transpiration demand
  - However, more plants equals more maintenance needed and potential decaying OM…it’s a balance!

https://bluegrasslawn.com/msd-bio-retention

To mulch, or not to mulch?

- Mulch removes hydrocarbons
- Nutrient leaching potential
  - Free of soil, roots, plant clippings and debris
- Floating
  - Single, double or triple?
  - Conduct floatability test – put it in a bucket and stir!
- Suggest certification, if spec'ing
  - US - Mulch and Soil council
  - https://www.mulchandsoilcouncil.org/

Bioretention – Nutrient Removal

<u>Media additives & Nutrient removal</u>

- Media additives
  - WTRs, aluminum and or iron oxyhydroxides
    - Toxicity testing: Cu export from WTRs
  - Can also limit P sent to Plant, so important to keep ratio right
- Biochar?
  - Can work well, but more research needed
  - Sourcing and pyrolyzing to spec, scaling, are issues

https://stormwater.pca.state.mn.us/index.php/Design_criteria_for_iron_enhanced_sand_filter

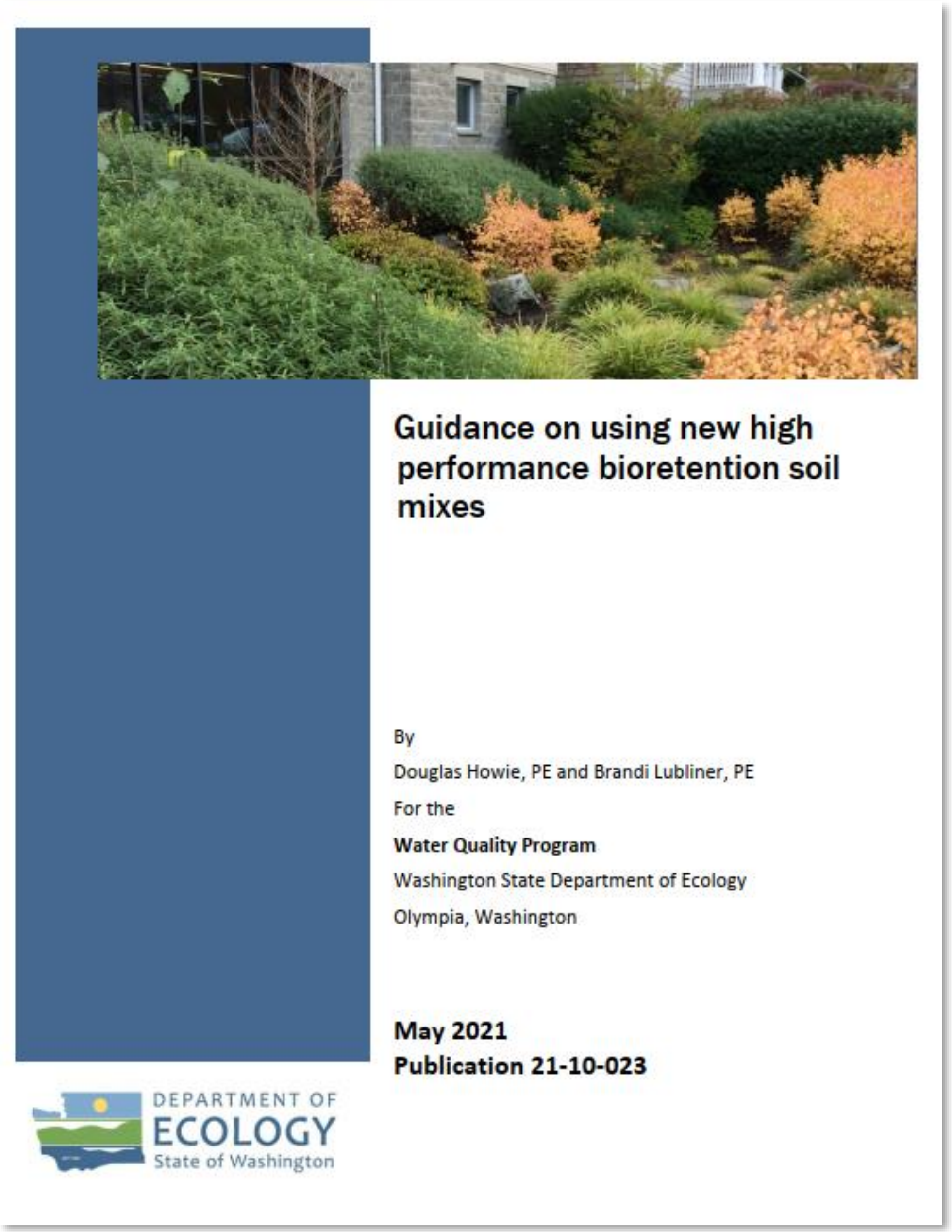
CONTECH ENGINEERED SOLUTIONS

Washington State Department of Ecology

- 2013 letter to stop using bioretention which discharges to P sensitive receiving waters
  - 60/40 spec leaches P and Cu during first 2 yrs
- 8-yr media study result: *"High Performance Bioretention Soil Media"* (HPBSM)
  - **Bench-scale tested only**
  - Field testing results TBD
- https://apps.ecology.wa.gov/publications/SummaryPages/2110023.html

"Phosphorus sensitive receiving waters"

- How do we define? If we don't change specs now, will we contribute to P impairment?
- Proactive vs reactive design


Guidance on using new high performance bioretention soil mixes

By

Douglas Howie, PE and Brandi Lubliner, PE

For the

Water Quality Program

Washington State Department of Ecology

Olympia, Washington

May 2021

Publication 21-10-023

DEPARTMENT OF ECOLOGY State of Washington

Bioretention – Nutrient Removal

3 types of HPBSM blends

- **Type I**= Solids & metals
- **Type II**= Solids, metals, phosphorus
- **Type III**= Solids, metals, phosphorus, and "additional LID and WQ objectives"
  - Compost for plants

Table 1. Approved high performance BSM (HPBSM) for runoff treatment in bioretention

Performance Goals for Runoff Treatment	Achieves suspended solids treatment (≥80% reduction)	Achieves dissolved metal treatment (≥30% copper and ≥60% zinc reduction)	Achieves phosphorus treatment (≥50% reduction)	Achieves additional LID objectives and water quality objectives [a]
Type 1: 18" HPBSM Primary layer. HPBSM primary layer consists of 70% sand, 20% coir, and 10% high carbon wood ash (biochar) by volume.	X	X		
Type 2: 18" HPBSM Primary layer plus 12" HPBSM Polishing Layer. HPBSM Polishing layer consists of 90% sand, 7.5% activated alumina, and 2.5% iron aggregate by volume.	X	X	X	
Type 3: 18" HPBSM Primary Layer plus 12" HPBSM Polishing Layer plus 2"Compost Surface Layer [b, c]. Compost must meet bioretention compost specifications in Ecology's stormwater manuals.	X	X	X	X

[a] The 2" Compost Surface layer is anticipated to improve success of plantings, due to improved water holding capacity (McIntyre et al., 2020). Additionally, based on the King County and Herrera, 2020 study this mix was successful in meeting all treatment goals (basic, copper, zinc, and phosphorus) as well as some protection against the acute toxicity to *C. dubia* and *D. rerio* found in the influent (untreated) stormwater.

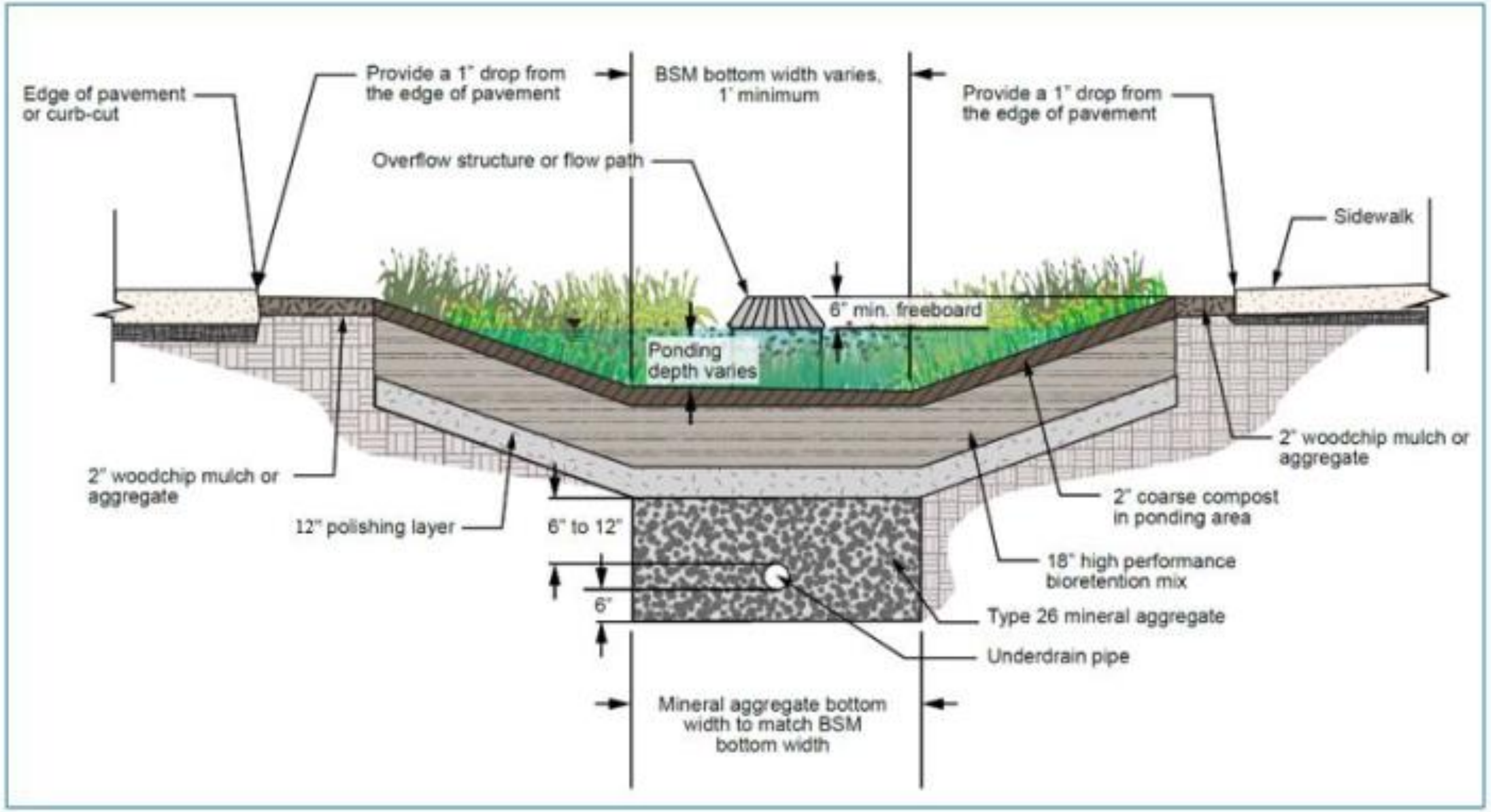
[b] Do not use the HPBSM Primary Layer (Type 1) with the Compost Surface Layer without the HPBSM Polishing Layer. The HPBSM Polishing Layer is necessary to limit phosphorus and nitrogen export from the Compost Surface Layer.

[c] Carbon or organic matter components of the mixes such as compost and mulch are believed to be an important factor to capture organic compounds in stormwater runoff (King County and Herrera, 2020, McIntyre et al., 2020).

Bioretention – Nutrient Removal

- Filtration rate
  - 12”/hr (300mm/hr) design rate
  - Apply safety factors as needed
- 18” high performance mix
  - 70% sand
  - 20% coir
  - 10% high carbon wood ash (biochar)
- 12” polishing layer
  - 90% sand
  - 7.5% alumina
  - 2.5% iron

Figure 2. Typical Cross Section of Type 3 HPBSM



How will this be implemented/enforced?

Ecology anticipates incorporating these alternatives for BSM in the bioretention BMP design when we next update the stormwater manuals. Ecology requests that project proponents report back any issues they may have with obtaining materials that meet these specifications so that we can further refine the criteria prior to the next manual updates.

Bioretention – Nutrient Removal

CONTECH ENGINEERED SOLUTIONS

Filter sand

- Who provides test data?
- Who checks test data?
- Manufacturers (quarry) may test periodically, Ecology suggests project-specific material be tested (contractor?)
- Cost of leaching tests?
  - Toxicity Characteristic Leaching Procedure (TCLP) is similar
  - Approx $700-1000 per sample

Sieve Size	Percent Passing Min.	Percent Passing Max.
3/8”	99	100
No. 4	95	100
No. 8	68	86
No. 16	47	65
No. 30	27	42
No. 50	9	20
No. 100	0	7
No. 200	0	2.5

Test / Method	Testing Responsibility [a]	Criterion	Requirement
Synthetic Precipitation Leaching Protocol (EPA Method 1312) and EPA Method 353.2	Proponent	NO3+NO2	0.15 mg/L (Max.)
Synthetic Precipitation Leaching Protocol (EPA Method 1312) and NEMI Method SM 4500-P E-99	Proponent	Total Phosphorus	0.15 mg/L (Max.)
		Ortho-phosphorus	0.15 mg/L (Max.)
Synthetic Precipitation Leaching Protocol (EPA Method 1312) and EPA Method 200.8 UCT-KED	Proponent	Copper	10 µg/L (Max.)

[a] Though the supplier will provide many of the tests indicated in this table, project proponents are encouraged to test the exact material which will be provided for their projects. Supplier tests are only run periodically on the source material not on the exact material supplied for the project. This is particularly important for the aggregate gradation which has the strongest influence on system hydraulics.

Bioretention – Nutrient Removal

Coconut Coir Fiber

- Who provides test data?
- Who checks test data?
- Manufacturers may test periodically, Ecology suggests project-specific material be tested (contractor?)
- Cost of leaching tests?
  - Toxicity Characteristic Leaching Procedure (TCLP) is similar
  - Approx $700-1000 per sample

Test / Method	Testing Responsibility [a]	Criterion	Requirement
Synthetic Precipitation Leaching Protocol (EPA Method 1312) and EPA Method 353.2	Proponent	NO_3+NO_2	0.15 mg/L (Max.)
Synthetic Precipitation Leaching Protocol (EPA Method 1312) and NEMI Method SM 4500-P E-99	Proponent	Total Phosphorus	0.15 mg/L (Max.)
		Ortho-phosphorus	0.15 mg/L (Max.)
Synthetic Precipitation Leaching Protocol (EPA Method 1312) and EPA Method 200.8 UCT-KED	Proponent	Copper	10 µg/L (Max.)
Test Methods for the Examination of Compost and Composting (TMECC) Method 04.10-A	Manufacturer	Electrical Conductivity	1.0 mmhos/cm (Max.)

[a] Though the manufacturer will provide many of the tests indicated in this table, project proponents are encouraged to test the exact material which will be provided for their projects. Manufacturer tests are only run periodically on the source material not on the exact material supplied for the project.

CONTECH ENGINEERED SOLUTIONS

High Carbon Wood Ash (Biochar)

- Who provides test data?
- Who checks test data?
- Manufacturers may test periodically, Ecology suggests project-specific material be tested (contractor?)
- Cost of leaching tests?
  - Toxicity Characteristic Leaching Procedure (TCLP) is similar
  - Approx $700-1000 per sample
- Cost of additional tests for biochar?

Test / Method	Testing	Criterion	Requirement
Synthetic Precipitation Protocol (EPA Method 131 Method 353.2			
Synthetic Precipitation Protocol (EPA Method 131 Method SM 4500-P			
Synthetic Precipitation Protocol (EPA Method 131 Method 200.8 UCT-			
Total C and H analysis combustion-elemental an Method 440.0). Inorganic determination of CO_2-C con HCl, as outlined in ASTM Standard Test Method f Determination of Carbonat Soils. Organic C calculated Inorganic C.			
Proximate Analysis (ASTI			
Metals (EPA Method			

		Cadmium	10 ppm (Max.)
		Lead	150 ppm (Max.)
		Mercury	8 ppm (Max.)
		Molybdenum	9 ppm (Max.)
		Nickel	210 ppm (Max.)
		Selenium	18 ppm (Max.)
		Zinc	1400 ppm (Max.)
Total polycyclic aromatic hydrocarbons by US EPA 8270 (2007) using Soxhlet extraction (US EPA 3540) and 100% toluene as the extracting solvent	Manufacturer	PAH	300 ppm (Max.)
Dioxins/Furans TEQ EPA 8290 (2007)	Manufacturer	PCDD/Fs	17 ppb WHO-TEQ [b] (Max.)
Cation Exchange Capacity (USEPA Method 9081)	Manufacturer	milliequivalents CEC/100 g dry soil	Report
Gradation (ASTM D422)	Manufacturer	# 6	100% Passing
		#100	10 % Passing (Max.)

[a] Though the manufacturer will provide many of the tests indicated in this table, project proponents are encouraged to test the exact material which will be provided for their projects. Manufacturer tests are only run periodically on the source material not on the exact material supplied for the project.

[b] Toxic Equivalency (TEQ) is calculated by multiplying the concentration of each PCDD/F by its World Health Organization (WHO) Toxic Equivalency Factor (TEF) and summing the products.

CONTECH ENGINEERED SOLUTIONS

HPBSM Polishing Layer

- Who provides test data?
- Who checks test data?
- Manufacturers may test periodically, Ecology suggests project-specific material be tested (contractor?)
- Cost of leaching tests?
  - Toxicity Characteristic Leaching Procedure (TCLP) is similar
  - Approx $700-1000 per sample
- Cost of additional tests for alumina?

Component	Ratio (by volume)
Filter Sand	91% (+/- 1%)
Activated Alumina	6.5% (+1% / - 0%)
Iron Aggregate	2.5% (+0% / -0.25%)

Activated Alumina

The Activated Alumina should meet the following requirements for quality and grading:

Test / Method	Testing Responsibility [a]	Criterion	Requirement
Synthetic Precipitation Leaching Protocol (EPA Method 1312) and EPA Method 353.2	Proponent	NO_3+NO_2	0.1 mg/L (Max.)
Synthetic Precipitation Leaching Protocol (EPA Method 1312) and NEMI Method SM 4500-P E-99	Proponent	Total Phosphorus	0.1 mg/L (Max.)
		Ortho-phosphorus	0.1 mg/L (Max.)
Synthetic Precipitation Leaching Protocol (EPA Method 1312) and EPA Method 200.8 UCT-KED	Proponent	Copper	1 µg/L (Max.)
Producer Analysis	Manufacturer	Alumina (Al_2O_3) content	90% (Min.)
	Manufacturer	Bulk density	760 Kg/m³ (Min.)
	Manufacturer	Surface area	300 m²/g (Min.)
Gradation (ASTM D422)	Manufacturer	#14 US Standard Sieve	100% Passing
	Manufacturer	#28 US Standard Sieve	0% Passing

[a] Though the manufacturer will provide many of the tests indicated in this table, project proponents are encouraged to test the exact material which will be provided for their projects. Manufacturer tests are only run periodically on the source material not on the exact material supplied for the project.

Bioretention – Nutrient Removal

CONTECH ENGINEERED SOLUTIONS

HPBSM Polishing Layer

- Who provides test data?
- Who checks test data?
- Manufacturers may test periodically, Ecology suggests project-specific material be tested (contractor?)
- Cost of leaching tests?
  - TCLP is similar, $700-1000 per sample
- Cost of additional tests for iron?

Component	Ratio (by volume)
Filter Sand	91% (+/- 1%)
Activated Alumina	6.5% (+1% / - 0%)
Iron Aggregate	2.5% (+0% / -0.25%)

Iron Aggregate

The Iron Aggregate should be ground Iron meeting the following requirements for quality and grading:

Test / Method	Testing Responsibility [a]	Criterion	Requirement
Synthetic Precipitation Leaching Protocol (EPA Method 1312) and EPA Method 353.2	Proponent	NO3+NO2	0.1 mg/L (Max.)
Synthetic Precipitation Leaching Protocol (EPA Method 1312) and NEMI Method SM 4500-P E-99	Proponent	Total Phosphorus	0.1 mg/L (Max.)
	Proponent	Ortho-phosphorus	0.1 mg/L (Max.)
Synthetic Precipitation Leaching Protocol (EPA Method 1312) and EPA Method 200.8 UCT-KED	Proponent	Copper	1 µg/L (Max.)
Producer Analysis	Manufacturer	Iron Content by weight	80% - 97%
Gradation (ASTM D422) or Producer Analysis	Manufacturer	#4	100% passing
	Manufacturer	#8	95 -100% passing
	Manufacturer	#16	75-90% passing
	Manufacturer	#30	25-45% passing
	Manufacturer	#50	0-10% passing
	Manufacturer	#100	0-5% passing
	Manufacturer	#200	0-2.5% passing

[a] Though the manufacturer will provide many of the tests indicated in this table, project proponents are encouraged to test the exact material which will be provided for their projects. Manufacturer tests are only run periodically on the source material not on the exact material supplied for the project.

Blending, Delivery, Protection, and Placement

- Contractor provides plan for designer to review
- Checked by city or EOR?

Blending, Delivery, Protection, and Placement

The blending, handling, and placement of the HPBSM Primary and Polishing Layers needs to be done carefully to ensure a successful installation. The contractor should prepare a Blending, Delivery, Protection, and Placement plan and submit it to the designer for review. The HPBSM Primary and Polishing HPBSM Layer media shall be mechanically blended to produce a homogeneous mix by a blending vendor/contractor with soil blending experience. The blending should occur on an impervious (asphalt or concrete) surface pad that has been thoroughly washed clean (e.g., pressure washed) prior to blending or in purpose-built soil blending equipment that has been washed. The blending pad shall be large enough to be able to turn and mix the media without introducing contamination. The blending pad shall be free of standing water before blending and shall be protected from stormwater run-on from areas off of/adjacent to the pad.

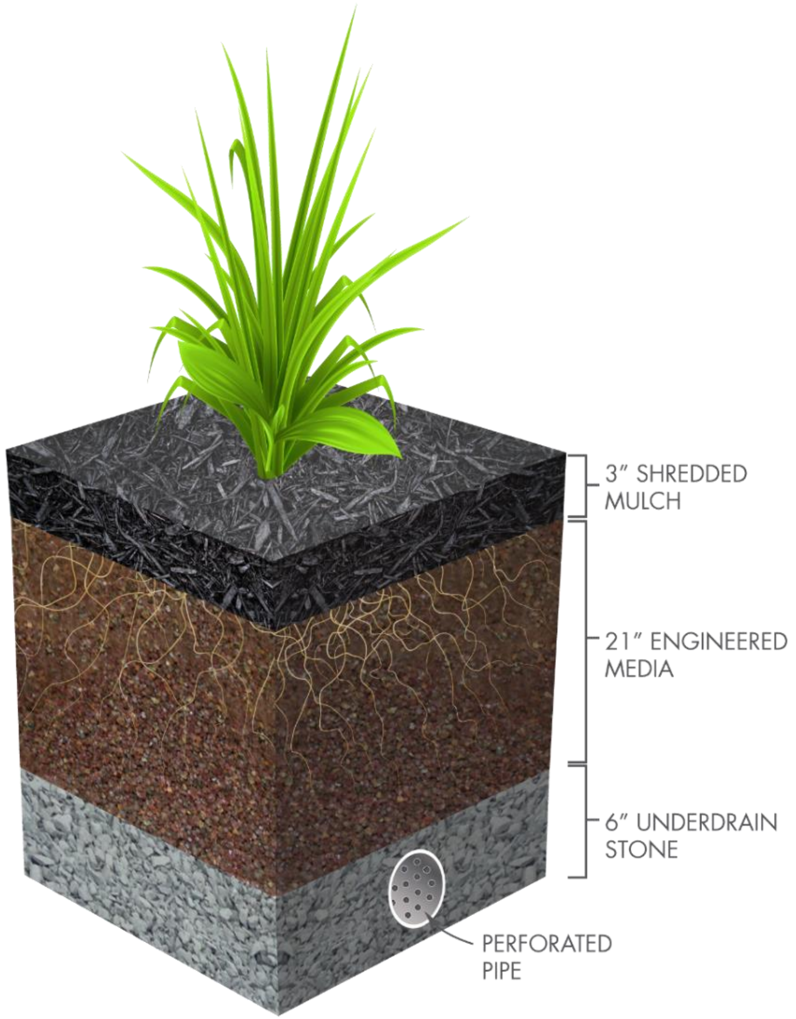
The measurement of the components to be blended shall be by dry weight on scale equipment capable of measuring within 1 pound or in full vessels of a known volume. Estimating the volumes of materials of partially full buckets or vessels shall not be used. Prior to blending, the coconut coir fiber shall be loose and hydrated such that its density is 4-5 pounds per cubic foot. The materials shall be blended until they are in a homogenous mixed state and then protected from contamination or saturation during storage, delivery, stockpiling, and placement.

The HPBSM layers should not be placed if the area is frozen, has standing water, is excessively wet or saturated, or has been subjected to more than 1/2 inch of precipitation within 48 hours before placement, unless approved otherwise by the Engineer. Do not place the HPBSM layers if adequate temporary erosion and sediment control measures are not in place to protect the media from contamination by silt laden run-off.

Place HPBSM layers loosely and evenly, no deeper than these specifications unless otherwise approved by the Engineer, on a properly prepared subgrade. After each lift, rake the surface to a uniform grade. Consolidate the entire surface area of each lift by boot compaction or a lawn roller and rake again to scarify before placing subsequent lifts or planting.

"Pre-engineered and pre-packaged stormwater biofiltration treatment which optimizes public domain components to reliably achieve long-term pollutant reduction at higher loading rates:"

1. Pretreatment top layer (mulch)
2. **Engineered high flow biofiltration media (100-175"/hr) (2500-4500mm/hr)**
3. Underdrain system
4. Landscape vegetation



WA TAPE Test Site- Bellingham, WA

Lake Whatcom Watershed
Evaluation Period 2013

Bioretention Performance

International Stormwater BMP Database 2020 Summary Statistics

- Field monitoring results
- High rate biofiltration (HRBF) included for first time
- Still lacks equivalent monitoring protocols, however best reference currently available
- ALL 5 HRBF field studies are Filterra

Bioretention Performance

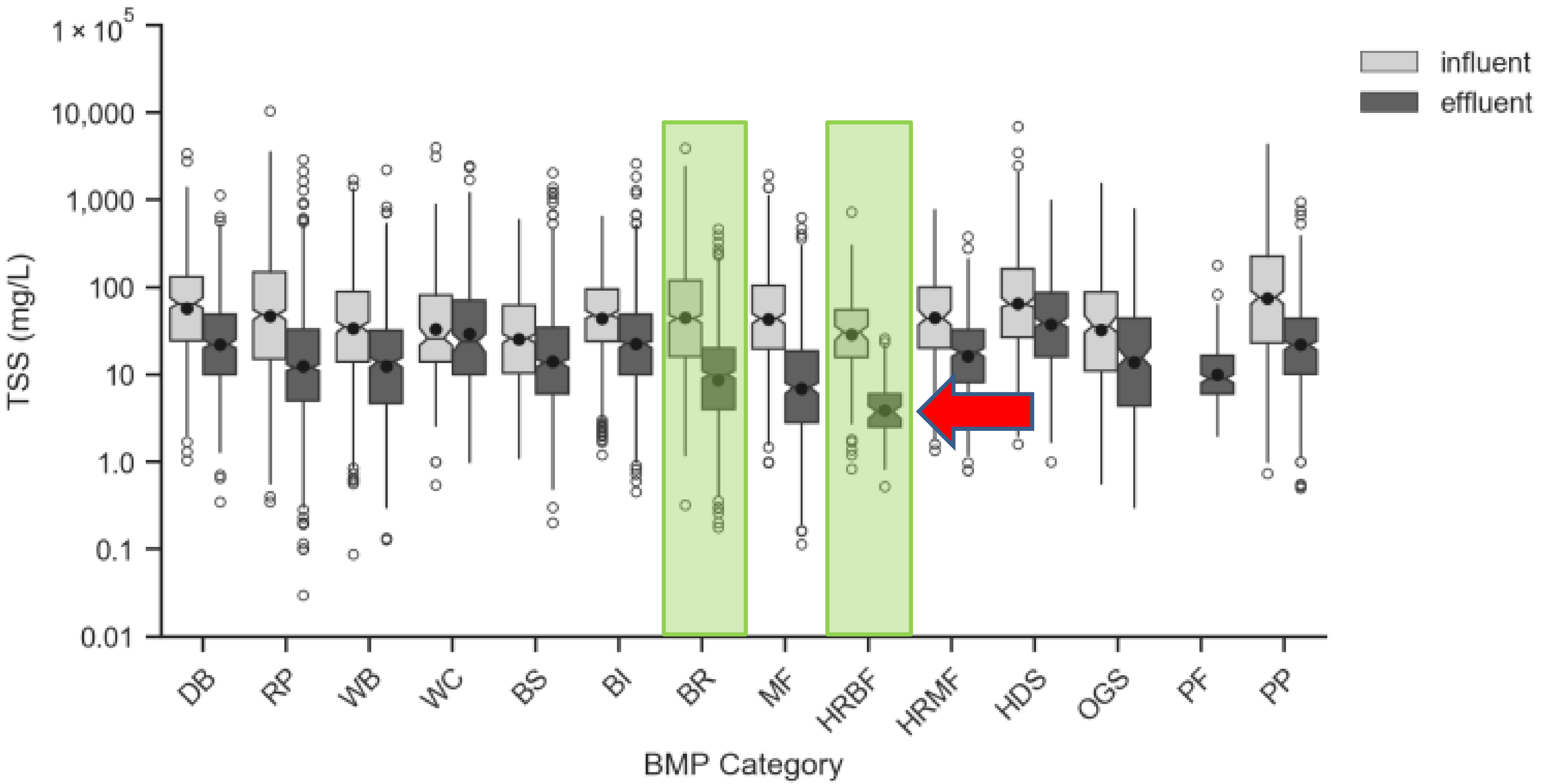


Figure 2-2. Box Plots of Influent/Effluent TSS (mg/L).

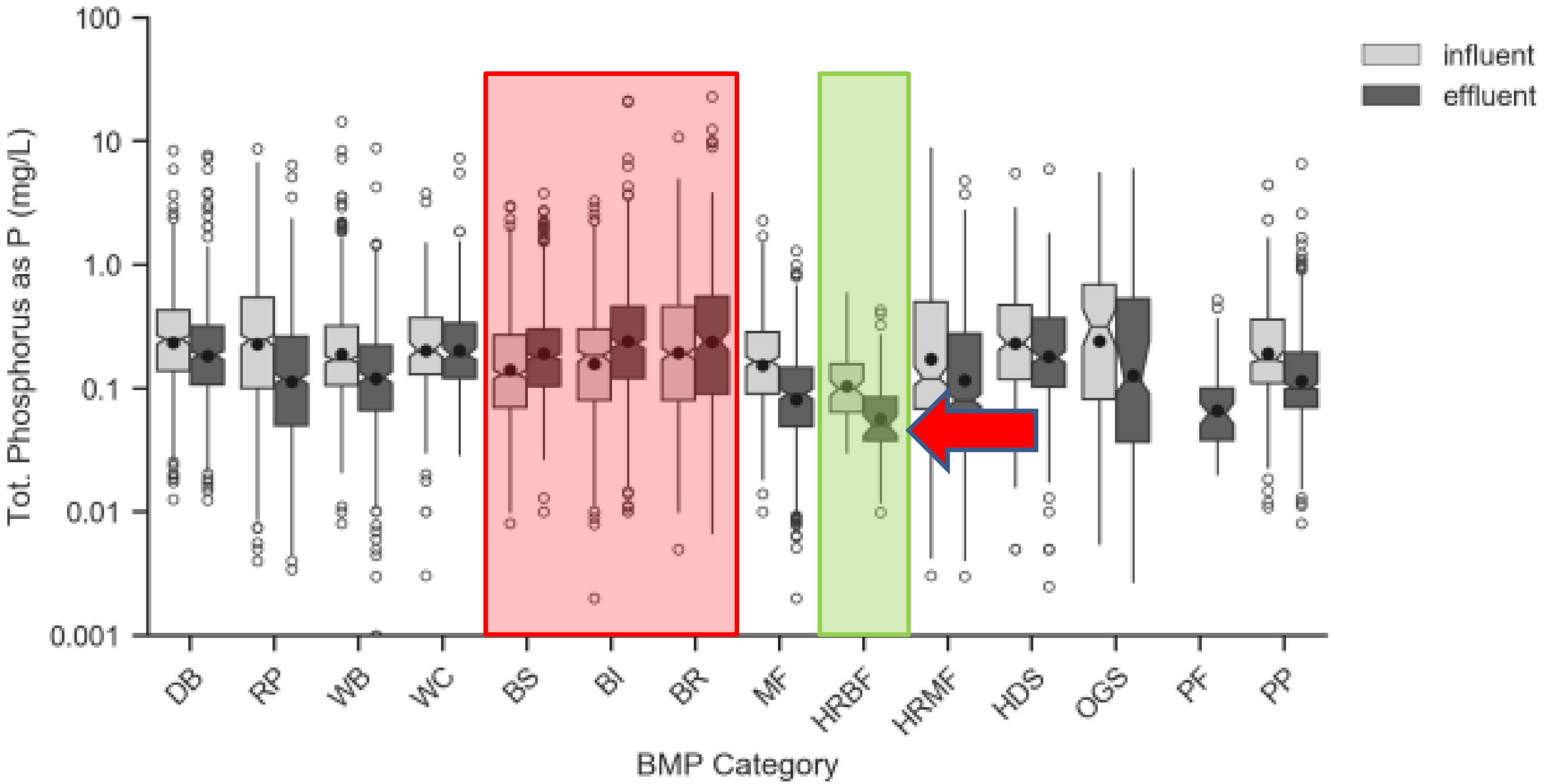


Figure 4-3. Box Plots of Influent/Effluent Total Phosphorus as P (mg/L).

Next Steps – Public Domain BRT Trials

MS Thesis summary

- Need: long term performance and maintenance protocol representative of actual conditions
  - Manufactured and conventional treatment systems
  - NJDEP (lab)
  - TAPE (field)
  - STEPP/ASTM
- Mass load capacity with oil+ organics
  - High rate biofiltration
  - Conventional biofiltration

Mass Load Capacity Testing – HRBF Oil + Organics

- Influent Characterization
  - Avg TSS = 100 mg/L
  - Avg SSC = 196 mg/L
  - Avg TVSS = 17.5 mg/L
  - Avg oil = 7.5 mg/L
  - Mass Load SSC = 426 mg/L
- Hypothesis confirmed
- Next steps
  - Develop SOP for synthetic SW mass load capacity testing
  - Determine influence of
    - organics
    - vegetation
    - antecedent periods

Conclusions

- US public agencies taking steps to improve bioretention specifications
  - QC, lab costs, and enforcement/oversight will be a challenge
- Filterra high rate biofiltration has proven pollutant removal performance in the field
  - Complicated media spec work, procurement, enforcement, and installation issues are eliminated
- More data needed on long term performance and maintenance triggers
  - Coming soon!

Questions?

Thank you!

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