Treatability of Filtered Heavy Metals by (Bio)(In)Filtration Media: Water and Soil Chemistry Effects

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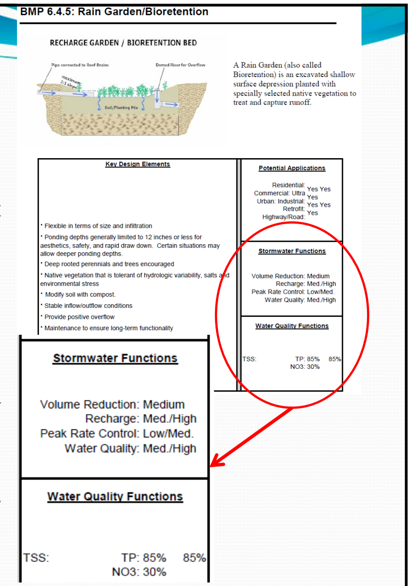
Introduction

- Biofiltration typically reduces water volume and some pollutant loads through plant uptake and pore space retention in the media.
- Many guidance documents apply expected pollutant removals based on literature.
  - However, typically presented as efficiencies of removal and have been misinterpreted and misapplied.
  - Also difficult to remove 85% of pollutants in "clean" water.
  - Do not address metals removal.



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Introduction

- Predicting the pollutant removal potential of (bio)(in)filtration media requires understanding soil AND water chemistry, including influent runoff chemistry.
- But … Guidance documents typically have very generic media specifications and do not provide guidance regarding media that address the active processes occurring in device (physical straining plus potentially biogeochemical processes).

> 2. **Planting Soil** should be a loam soil capable of supporting a healthy vegetative cover. Soils should be amended with a composted organic material. A typical organic amended soil is combined with 20-30% organic material (compost), and 70-80% soil base (preferably topsoil). Planting soil should be approximately 4 inches deeper than the bottom of the largest root ball.
>
> 3. **Volume Storage Soils** should also have a pH of between 5.5 and 6.5 (better pollutant adsorption and microbial activity), a clay content less than 10% (a small amount of clay is beneficial to adsorb pollutants and retain water), be free of toxic substances and unwanted plant material and have a 5 –10% organic matter content. Additional organic matter can be added to the soil to increase water holding capacity (tests should be conducted to determine volume storage capacity of amended soils).

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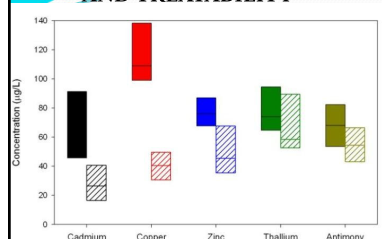
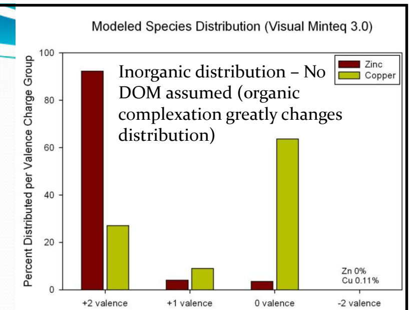
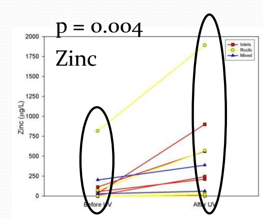
INFLUENT WATER QUALITY AND TREATABILITY





What form are those compounds that pass through a 0.45-µm filter?



	% Ionic	% Bound
Zinc	15	85
Copper	70	30
Cadmium	10	90
Lead	12	88

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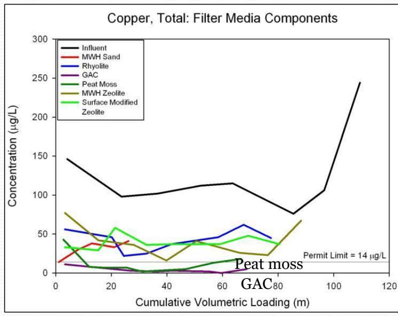
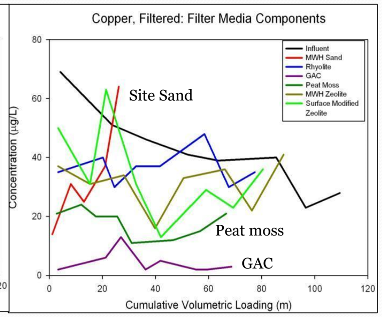
Initial Design Question: Pollutant Form – Particulate Associated or Dissolved/Colloidal?





- Good overall removal of total copper, but much poorer removal of filtered copper – function of particulate associations.
- For dissolved copper, removal greatest in GAC and peat moss, likely resulting from multiple types of binding sites available in media. Note poorer performance comparatively of zeolites, indicating ion exchange occurs, but not only removal mechanism.

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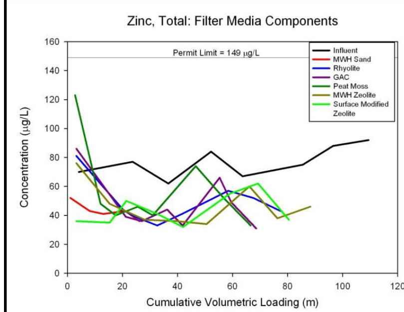

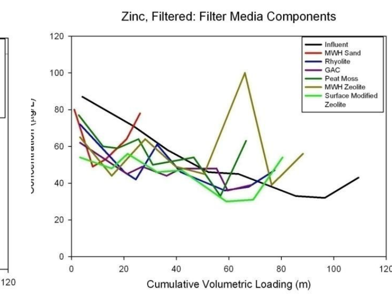

- Poor removal of total and filtered components – likely because most of the zinc was dissolved/colloidal.
- Model predicted mostly ionic +2 form, likely because OM effects ignored in model.
- Historical data has shown zinc 85% bound by organic matter.
- Zinc likely to form many complexes with Cl, OH, Cu, etc.

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Design for Treatment Contact Time

- Starting off with conflicting requirements:
  - Rapid infiltration to prevent flooding, protect against standing water, etc.
  - Slow infiltration to allow for sufficient time for pollutants to be removed from the water and adhered to the media.
  - These requirements are balanced by using depth filtration (sufficient media depth to ensure adequate contact).
- Soil physical characteristics that affect infiltration rate and contact time:
  - Texture, which affects the following (some states dictate soil texture class for infiltration devices):
    - Porosity
    - Bulk density
    - Permeability
  - Degree of compaction during and after construction (affects porosity, bulk density, permeability).
  - Degree of clogging (affects porosity, permeability)
- Choice of soil texture components to meet drain down time affects pollutant removals (chemical composition of media components).

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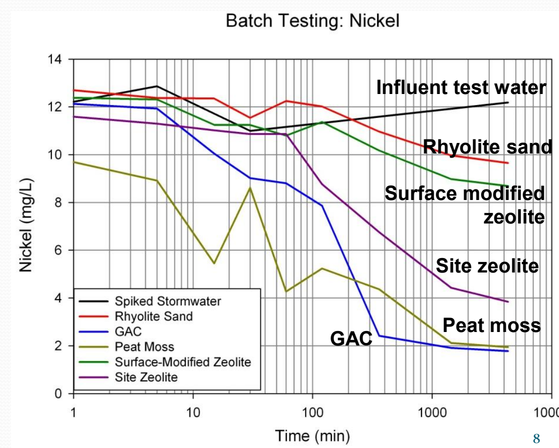
Batch Testing Results: Contact Time for Filtered Metals

- Minimal filtered metal removal when contact time <10 minutes (except peat).
- Optimal contact times removal ranged from 10 to 1,000 minutes, depending on metal and media type.



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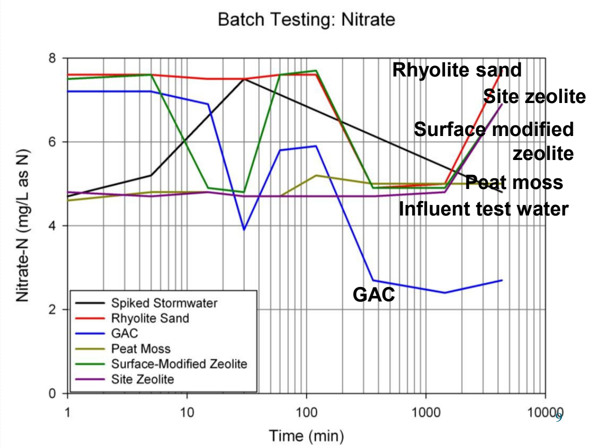
Batch Testing Results: Contact Time for Filtered Metals

- Only removal by GAC column.
- GAC removal required > 20 minutes and fluctuated. Consistent removal after 100 minutes contact time.



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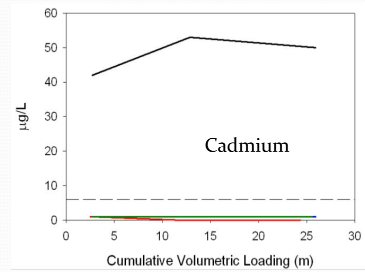
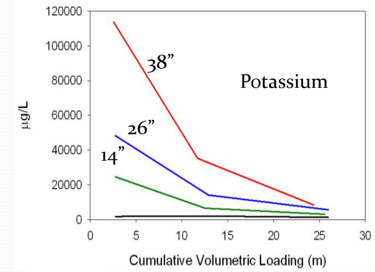
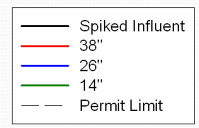
Initial Design Question: Contact Time Control Using Media Depth

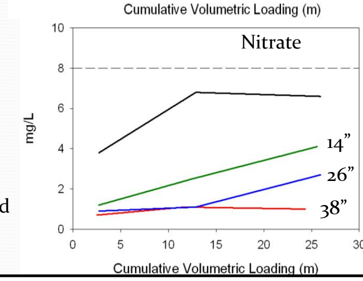






Example:
GAC-Sand

Results are media and parameter specific.



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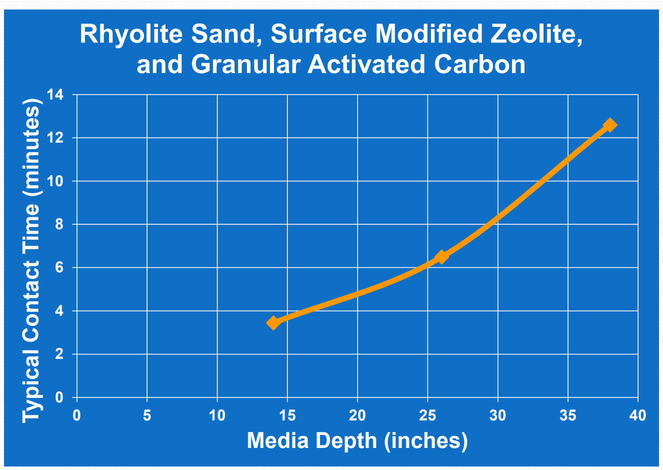
Initial Design Question: Translating Batch Results to Column Contact Time



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Soil and Water Chemistry Effects on Design to Be Considered

- Remove pollutants in the upper layers of the media. The deeper into the soil profile that the pollutants penetrate, the greater the likelihood of groundwater contamination or transport out of the device through an underdrain.
- Potential properties of interest in predicting removal (based on literature and batch-testing in the lab):
  - Soil and water pH
  - Pollutant forms (relationship to solids loading and PSD)
  - CEC (and AEC)
  - Mineral matter
  - Organic content
  - Phosphorus content
  - Oxidizing or reducing environment
  - Salinity and SAR

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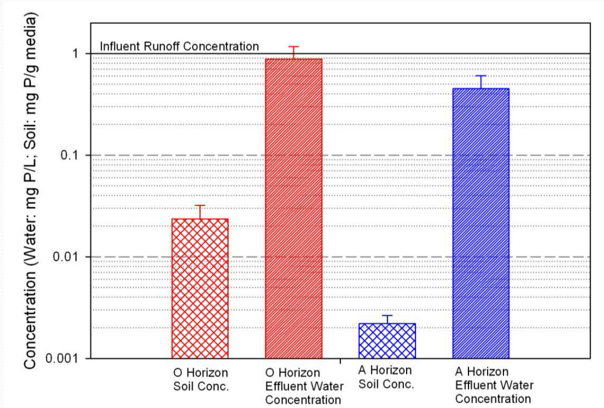
Impact of Initial Soil P Content



- Organic horizon has higher P content and minimal P removal.
- Mineral horizon has lower initial P content and thus P retention occurs.

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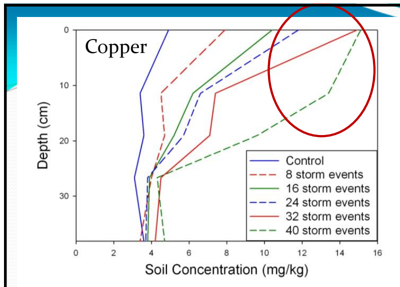
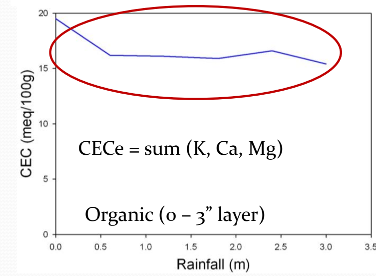
Breakthrough



- Copper Accumulation in Upper Layers of Soil with Subsequent Downward Migration
- Limited Release of CEC Cations or Decrease in CECe (sum of K, Ca, Mg)
- May be also complexation/chelation / exchange with organic compounds, which is not measured in CECe calculations

- Column testing breakthrough capacity = ~ 15 mg/kg
- Bench-scale batch capacity testing = ~ 45 mg/kg
- Difference potentially due to inability of/insufficient time for metal ions to migrate to inner pore spaces during flow-through operation and therefore, total removal ability of media not used.



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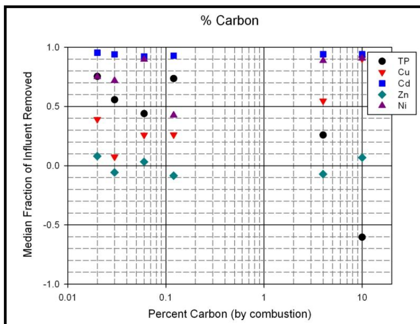
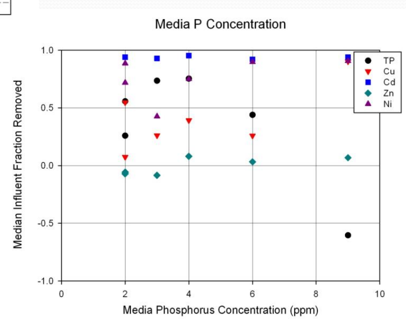


No trend seen in metals removal as a function of % soil C or % soil P until %C > 1 – 3% and soil P > 6 ppm.

Similar trends for all metals. Differences are in amount removed with smallest removal for zinc.

General trend of P removal decreasing as both % soil C and % soil P increase

Pollutant Removal: Function of Both Water and Soil Chemistry



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Observed Correlations Between Soil Parameters and Chemical Capacity (Batch Testing of 16 Media)

	Al	Ca	Cd	Cu	Fe	Ni	Mg	Mn	Zn	K	Cr	Tl	Sb	NH3	TP
Soil CEC			+	+	-	+			+	-		+			
Soil OM		+	+	+		+	+				-	+			
Soil C		+	+	+		+	+				-	+	+		
Soil N			+	+	-	+			+	-		+			-
Soil P			+		-	+			+	-				+	
Soil pH	+							+			+		+		
Soil K									+	-					
Soil Mg			+	+	-	+	+		+			+			
Soil Cu								-							
Soil S															
Soil Zn			+		-	+			+	-				+	-
Soil Ca			+		-	+			+						

Significance level of p = 0.05.

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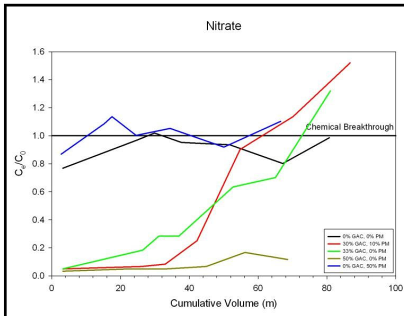
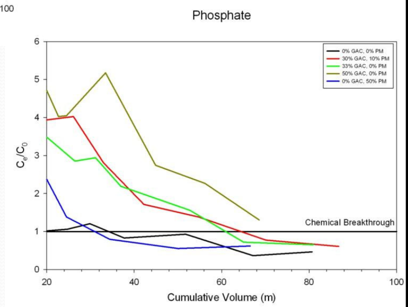


Trade-Offs in Media Mix Components and Ion-Exchange

- 0% GAC, 0% PM
- 30% GAC, 10% PM
- 33% GAC, 0% PM
- 50% GAC, 0% PM
- 0% GAC, 50% PM

Inverse removal behavior of nitrate and phosphate.

Reducing GAC content reduces nitrate removal life, but decreases amount of phosphate released.



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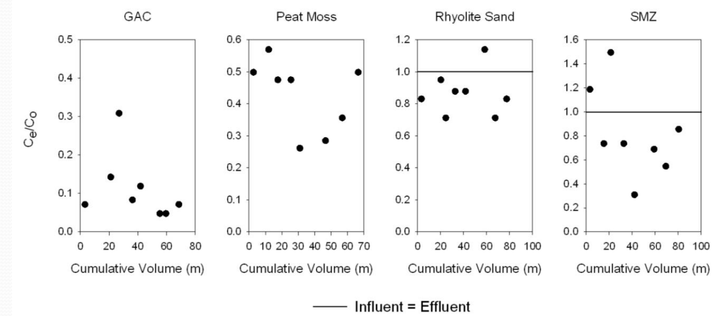
Selecting the Media Mixture from a Set of Potential Components: "Dissolved" Copper Example



- Model prediction: 25% +2 valence, 10% +1 valence, 65% 0 valence charge.
- Sand with modification: prefers ion exchange (+2 charge)
- Zeolite (SMZ) ion exchange resin (+2 charge)
- GAC and peat moss have multiple types of exchange/adsorption sites – good for all valence charges; GAC performing better for filtered copper

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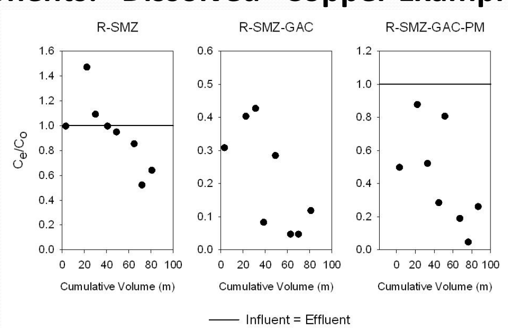
Selecting the Media Mixture from a Set of Potential Components: "Dissolved" Copper Example



- Modified sand and zeolite mixture – best removal 50%, but generally poor removal.
- GAC and peat moss were better than sand and zeolite; GAC performing better for filtered copper, but may not support plant life
- Adding small amount of peat moss as organic matter for plant life support only slightly reduced performance.

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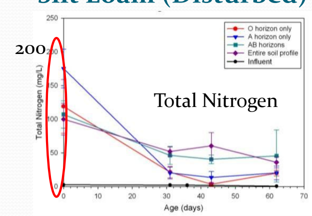
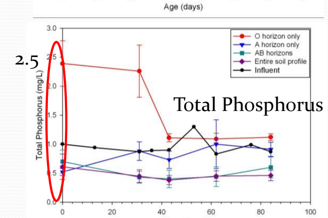
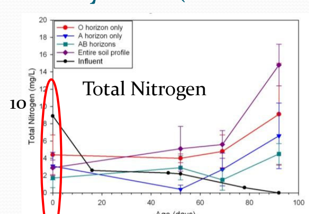
Impact of Soil Disturbance on Nutrient Release Immediately after Construction

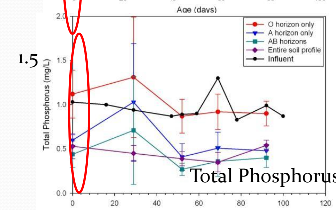
Silt Loam (Disturbed)





Loamy Sand (Undisturbed)





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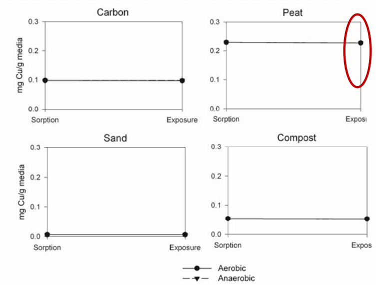
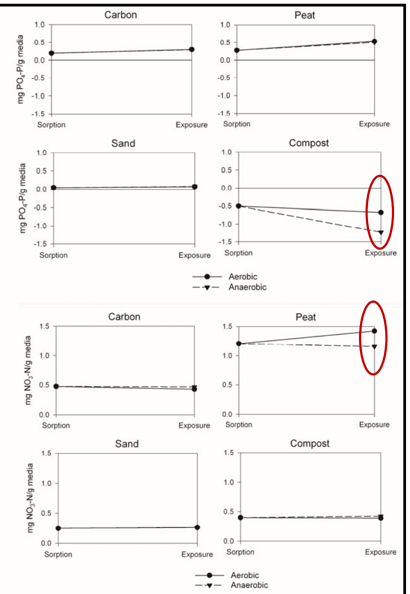
Additional Considerations: Changes in Soil and Porewater Chemistry between Storms





Heavy metals mostly retained.

Release of nutrients (N from peat [release captured N], P from compost [increased release]) under anaerobic conditions.

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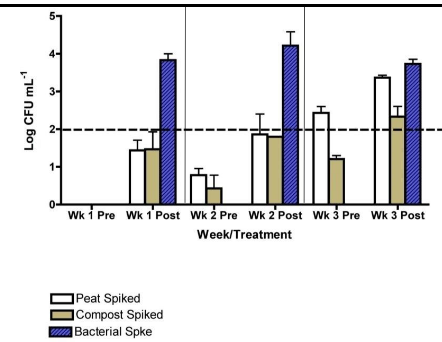
Bacteria Removal



Little difference between peat and compost.

Impact of OM content on retention and regrowth with little impact of pH change.

Initially, no coliform flush from peat (30% v/v) or compost (equivalent amount of OM). Retention after spiked stormwater passage approximately 2-log.

Weeks 2 and 3 pre-spike flush indicate a flushing out of captured bacteria (likely due to growth on media during inter-event period). Post-spike filtering showed concentrations near recreational water quality standards.

Week 3 first flush near WQS; after filtering, above WQS.

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Conclusions (to date)

- Most devices fail because of clogging.
  - Design for clogging first (assume with vegetation, solids loading for most media mixes approximately 25 kg/m²).
  - Maintenance has limited effectiveness. Vegetation likely will extend lifespan because of biological disturbance of soil.
- Evaluation of potential chemical removal.
  - Physical removal primary mechanism, even in media with "good" sorption/ion-exchange potential.
  - Removal based on influent quality (including "speciation" or "association" of pollutants with particulates of all sizes).
  - Evaluate media choices (either individually or as part of a mix) based on both adequate removal of pollutants and ensuring that the exchanged ions are not causing degradation.
    - CEC, AEC, OM, P-content, SAR, soil pH predict, but may not be able to quantify, removal efficiency or effluent quality. Also not precise measurements of lifespan.
    - Increasing OM and P content has an unquantified maximum effect. Above a certain amount, the media releases nutrients, color compounds, and colloids that may have associated pollutants.

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Acknowledgments

- The authors gratefully thank all the current and former students for their work on these projects.
  - Penn State Harrisburg: Dan Treese, Brad Mikula, Christine Siu, Danielle Harrow, Natasha Nicholson, Ryan Burrows, Mukesh Pratap
  - University of Alabama: Renee Morquecho, Noboru Togawa, Sree Usha
  - University of Alabama at Birmingham: Amanda Elledge, Carla Neggers, Blaine Collier, Mukesh Pratap
- We would also like to thank Ms. Betsy Graham for her tireless efforts spent analyzing the metals samples.
- Sponsors: U.S. EPA UWMB, WERF, GeoSyntec (and their industrial client)

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