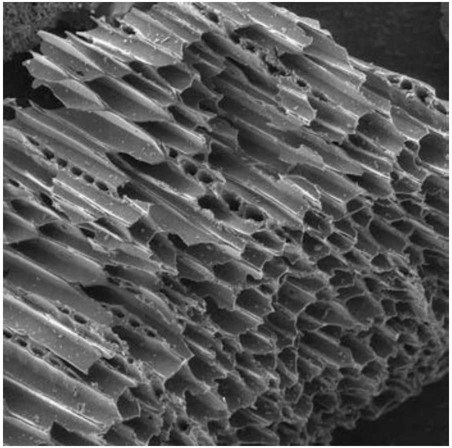
Biochar for Stormwater Treatment:

Technology Overview & Case Study Survey



Biochar 2016

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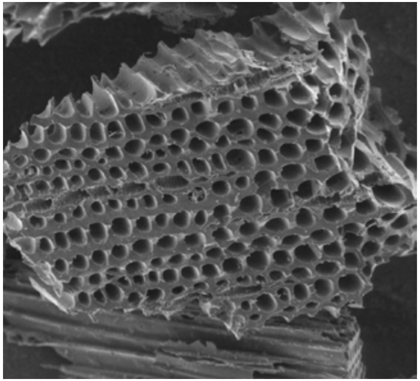
Biochar Physical Properties

Highly porous; surface area up to 500 m^2/g

3 distinct pore types:

1. External pores: Dependent on particle size

2. Macropores: Dependent on feedstock
   - 10-100 µm range for wood biochars



3. Micropores: Dependent on production
   - 1-10 nm range = 10-100 water molecules!
   - Majority of surface area with high potential sorption

Variety of sizes = remove range of sizes of aqueous and particulate contaminants

Biochar PhysioChemical Properties

Biochars are primarily stable Carbon Rings = Graphene Sheets

<u>Biomass:</u>
Lignin
Cellulose
Hemi-
Cellulose

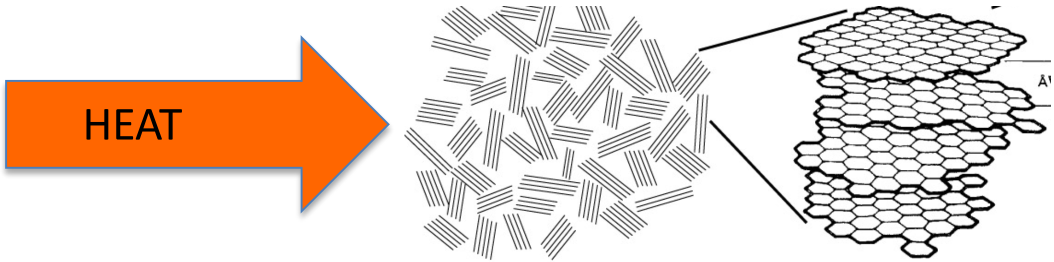


Image Sources: BEKbiochar

Carbon content in wood biochars > 80% typical

Also oxygen, hydrogen, and ash compounds: Mg, Ca, Si

Mineral ash content affects reactivity, pH, and salinity

- Nutrient and metal precipitates

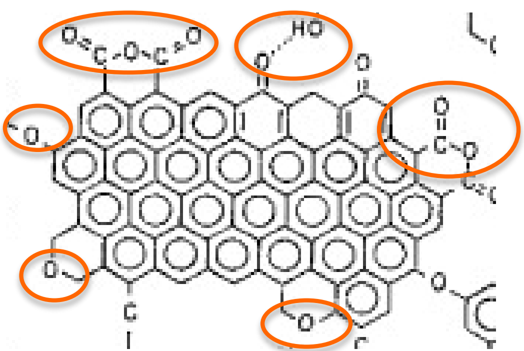
Biochar Sorption Properties

Biochars are primarily stable carbon rings = graphene sheets

- Can provide sorption of hydrophobic contaminants

Surface functional groups add reactivity

- Mostly oxygen-containing = cation exchange capacity
- Some anion exchange capacity



Environmental aging increases CEC

Biochar Type	CEC @ pH = 7 (meq/100 g)
Fresh	~10-20
Aged	~20-80
Historical	>100

Sorption capacity of Biochar could increase over time!

Image Source: BEKbiochar; Data Source: Cheng et al. 2006

Biochar Contaminant Removal

Contaminants	Removal Effectiveness	Removal Mechanisms
Heavy Metals (Cu, Zn, Pb, etc.)	Generally good but capacity may be limited	Cation exchange, surface sorption in nanopores, chemical precipitation
Nutrients	Variable; Depends on Nutrients and Biochar	Ion exchange, chemical precipitation
Trace Organics (PAHs, PCBs,	Good but variable, limited data	Surface sorption, other mechanisms possible
Organics = VOCs	Good but limited data	Surface sorption, other mechanisms possible
Bacteria	Excellent but limited data	Hydrophobic interactions

Most research has investigated aqueous phases contaminants

BUT for stormwater, filtration mechanisms remove particulates with associated pollutants

Stormwater Pollution Overview

Major source of water impairment

- Increased urbanization is root of problem
- Tightening regulations = increased attention
- Highly variable = difficult to treat

Numerous contaminants:

- Sediment/TSS
- Nutrients (N, P)
- Heavy Metals (Cu, Zn)
- Oil compounds
- Other organics
- Bacteria

Particulate-Bound: Contaminants attached to particles (>0.45 µm)

- Common for N, P, Metals

"Dissolved": Size fraction (<0.45 µm); Can be many forms

Stormwater Treatment Approaches

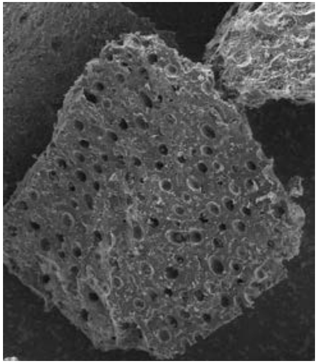
Media Filters

- High flow systems = small footprint
- Higher cost for high priority sites
- Media to remove contaminants
  - Target both dissolved and particulate
- **Biochar** as filtration media

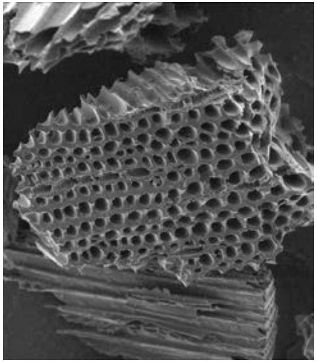
Biofiltration

- Low flow as Low Impact Development (LID)
- Lower cost but require more space
- Media to remove contaminants and support plant growth
- **Biochar** as component of biofiltration media
  - Removes contaminants
  - Support plant growth
  - Provides water holding

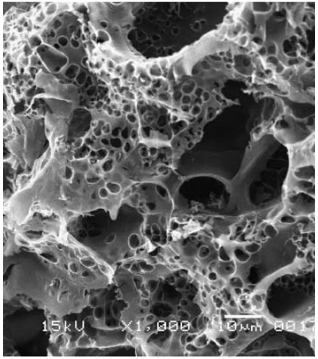
Design: Biochar is not Created Equal



Hazelnut Shell



Douglas-Fir



Cane Pith

Properties depend on feedstock and production conditions:

- Physical: surface area, pore sizes, hardness/friability
- Chemical: Reactivity, ash content
- Design Parameters: Sorption capacity, particle size, hardness

Material Screening is Critical

Can Pith Image Source: Tseng and Tseng, 2006

Design: Biochar Media Hydraulics

Raw biochar contains f**ine particles = clogging**

- May also leach contaminants and reduce removal

Rinsing or sieving for high flow applications

Particle size tradeoff:

- Coarser media = higher flow rate
- Finer media = More effective treatment

Blending can increase flow rate, but results can be mixed

- Process can also create fine particles = hardness matters

Low-flow bioretention: fine pose limited problem for flow rates, but may pose leaching issues

Design: Media Blends

Blended media often better choice:

- Enhance contaminant removal = multiple mechanisms and redundancy
- Adjust water chemistry
- Reduce media costs

Many Secondary Components:

- Inert: Sand, gravel, pumice
- Organic: Coconut coir, peat, compost
- Reactive: Zeolites, activated carbon

Bioretention media: Typically sand + organic + biochar

Media filters: Often include higher cost media

OSU Biochar Media Development

Lab-Based testing to develop media for copper and zinc removal

Collaborative research commercialization project:

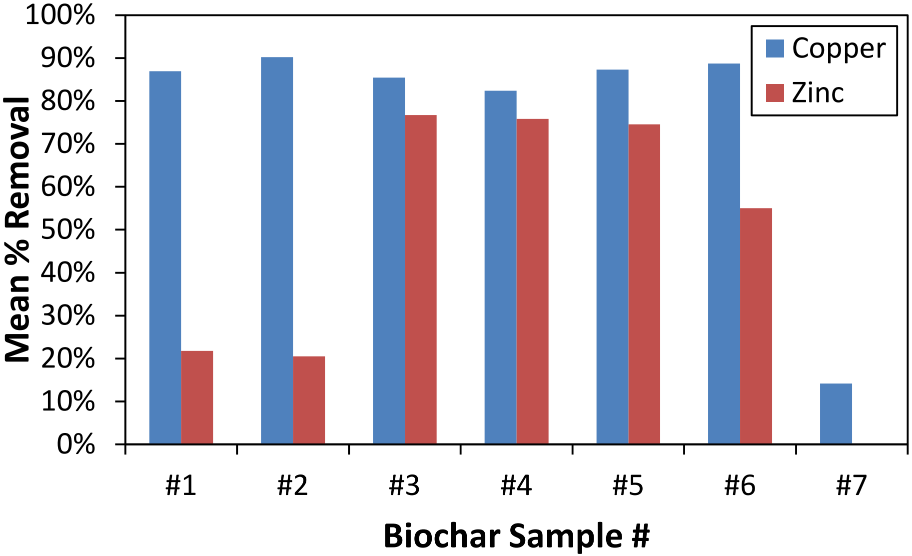
1. Select best biochar from available sources
   – Also assess processing requirements

2. Create and assess media blends
   – Using best biochar and secondary components

3. Fully characterize complete filtration blends
   – Contaminant removal, filter lifetime, hydraulics, pH, toxicity, etc.

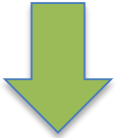
OSU Media Development Results

Started with lab testing of 7 Biochars



Good copper removal by most biochars

Zinc removal more variable



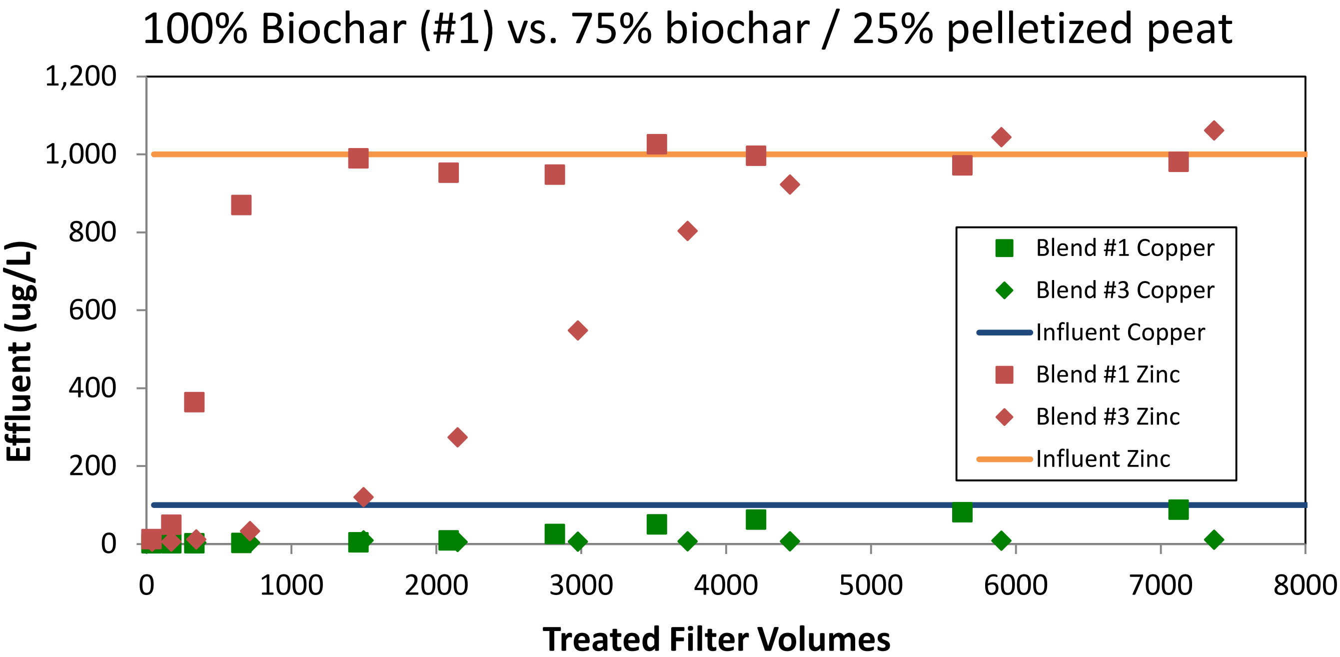
Most effective biochars used for further testing

Subsequent column testing to select best media blends

- Testing with real stormwater
- Intended for high flow media filters

OSU Final Media Characterization

Rapid Small Scale Column Tests (RSSCTs) to determine breakthrough



Pelletized peat dramatically improved zinc effectiveness

- How effective is biochar for high flow media?
  Different Biochar?   Include as minor component?

Port of Port Townsend Feasibility Study

Comprehensive Biochar Feasibility Study

Treatability Testing
Media Development → Pilot Testing
Device Testing → Full Level 3 Implementation
Installation and Monitoring

Biochar from nearby Port Townsend Paper Company Mill

- Rinsed, screened, and blended

Treatability testing for copper and zinc removal:

- Final mixture: ~80% rinsed biochar / 20% pelletized peat
  - Flow rate of 5-10 inches/minute = high flow media
  - Mean copper removal = 99.3%
  - Mean zinc removal = 99.5%

PoPT Pilot Testing

Pilot testing of upflow filter design

- Passive downspout filter using PT biochar media
- Design flow rate = 15 gpm
- Installed April 2014; 4 sampling events
- Estimated volume treated = ~10,000 gallons
- Device constructed by John Miedema

	Mean Influent ug/L	Mean Effluent ug/L	Benchmark ug/L	Mean Removal %
Total Copper	46.5	2.52	17	93.5%
Total Zinc	4925	7.46	120	99.8%

Below site discharge benchmarks

PoPT Full Installation

Full installation in December 2014

- 18 downspout treatment devices
- 2 custom-built in-ground filters
- Monitoring 2014-2015 rainy season
- Implementation by Jofran Enterprises

Downspout Filters Removal:

	Mean Influent ug/L	Mean Effluent ug/L	Mean Removal %
Total Copper	54.2	7.88	71.1%
Total Zinc	1018	39.0	92.6%

In-Ground Filters Removal:

	Mean Influent ug/L	Mean Effluent ug/L	Mean Removal %
Total Copper	2419	1336	52.6%
Total Zinc	1078	366	52.9%

Overall, Results Indicated:

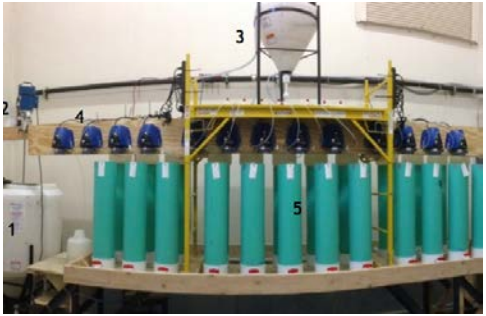
- Excellent removal with downspout filters
- Variable removal with in-ground filters
- **Media rinsing is critical** to improve flow rates and contaminant removal and to prevent leaching of fine particles
- Port Townsend biochar can cause a short-term nutrient pulse, especially unrinsed

Washington Bioretention Research

Multiple studies to investigate updates to state bioretention mixture

- In Response to P and Cu Leaching from Sand / Compost Mixture
- Two studies included biochar: Kitsap County and City of Redmond Projects

Kitsap County Bioretention Testing



1. Leaching of multiple bioretention components
   – Tested for N, P, and Cu to eliminate poor components
2. Leaching of media blends
3. Contaminant removal of blends
   – Tested for multiple stormwater pollutants

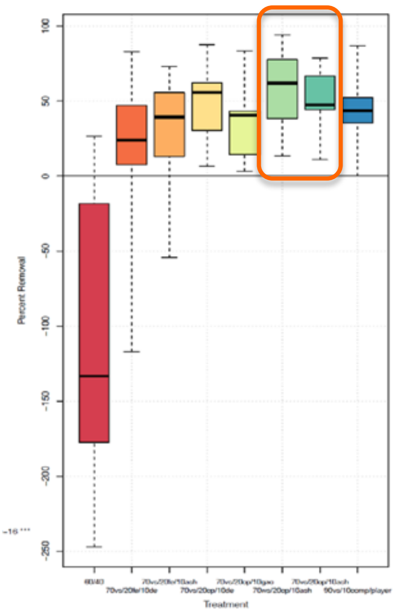
3 Component classes: Bulk aggregate, bulk organic ,organic additive

2 biochars included as organic additives

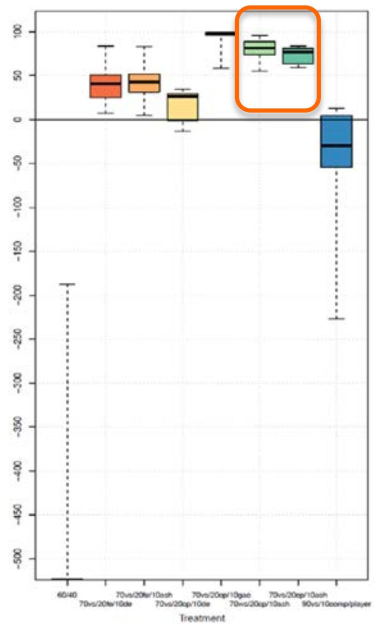
- ~~Unrinsed "Biochar"~~ → Leached high P
- Rinsed "High Carbon Fly Ash"

Image Source: Herrera Environmental Consultants, 2015

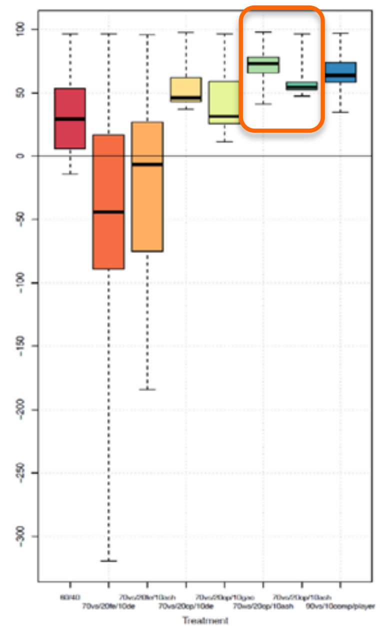
Kitsap County Bioretention Results



Total P



Total Cu



Nitrate + Nitrite

2 Biochar blends: 70% sand, 20% coconut coir, 10% fly ash (biochar)

- Different sand varieties
- Fly ash (biochar) among top performers

Conclusions

Biochar is a promising stormwater treatment approach

But MANY questions remain

Results for high flow media are promising but inconclusive

May be more effective as component of bioretention soil mixtures:

- Can provide long-term replacement for compost mixtures
- Contaminant removal may increase with ageing as CEC increases
- Provides plant growth and water holding benefits

Successful projects should consider:

- Biochar is not created equal = treatability testing and material screening
- Rinsing/Sieving to remove fines = higher flow rate and contaminant removal
- Media blends to improve performance
- Testing after implementation

Research Needs and Directions

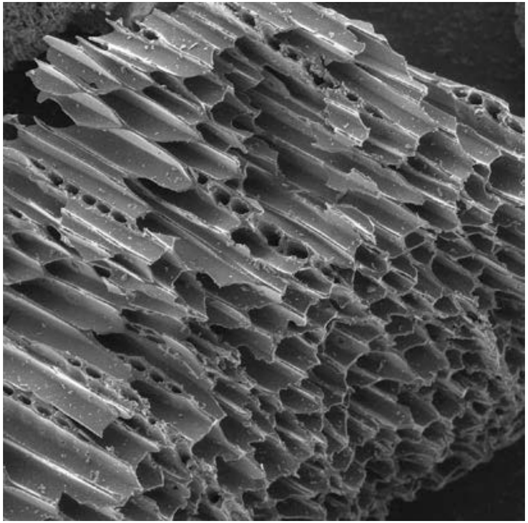
Laboratory research

- Contaminant removal mechanisms
- Filter longevity
- Stormwater / Biochar compatibility
- Emerging contaminants

Monitored Field Trials, Especially Biofiltration:

- Removal mechanisms including particulate removal
- Focus should be on long-term effectiveness vs. standard designs:
  - Does effectiveness of biochar media improve over time?
  - Do biochar-based mixtures (without compost) support plant growth?
  - Can inclusion of biochar increase system lifetime compared to compost

Questions?



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